# REPORT RESUMES

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# HARVARD PROJECT PHYSICS PROGRESS REPORT.

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THIS REPORT OF HARVARD PROJECT PHYSICS PRESENTS DRAFTS OF THREE SPEECHES DELIVERED TO THE AMERICAN ASSOCIATION OF PHYSICS TEACHERS (AAPT) MEETING, FEBRUARY, 1967. THE ADDRESS BY GERALD HOLTON DEALS WITH THE AIMS AND PROGRESS OF THE PROJECT. DISCUSSED ARE (1) PROJECT PARTICIPANTS, (2) AIMS AND CONTENT, (3) THE NEW EMPHASIS, (4) SURVEY OF COURSE CONTENT, (5) TITLES OF PROPOSED SUPPLEMENTAL UNITS, AND (6) PRINCIPLES OF SELECTION OF COURSE CONTENT. FOUR BASIC AIMS OF THE PROJECT ARE (1) TO PROVIDE A COHERENT, TESTED COURSE SUITABLE FOR USE ON A NATIONAL SCALE, AND INCORPORATING THE MOST DESIRABLE FEATURES OF BOTH PHYSICS AND PEDAGOGY WHICH HAVE NOT BEEN FORTHCOMING IN OTHER CURRICULUM PROGRAMS, (2) TO HELP RELIEVE THE DECLINE IN PHYSICS ENROLLMENTS, (3) TO PROVIDE TEACHERS WITH NECESSARY AIDS FOR GOOD PHYSICS TEACHING, AND GOOD PHYSICS AS DEFINED IN THE BROADEST HUMANISTIC WAY, AND (4) TO INCORPORATE THE NEWER CONCEPT OF THE TEACHER AND HIS INVOLVEMENT WITH THE CLASS. FLETCHER G. WATSON'S ADDRESS, "WHY DO WE NEED MORE PHYSICS COURSES," IS CONCERNED WITH DECLINING ENROLLMENTS IN PHYSICS. HE INDICATES A WAY TO ALLEVIATE THIS IS BY PROVIDING HIGH SCHOOL STUDENTS WITH AN EXCITING COURSE TREATING FUNDAMENTAL PHYSICAL IDEAS IN A HUMAN CONTEXT. F. JAMES RUTHERFORD'S TALK IS CONCERNED WITH "PROJECT PHYSICS IN THE CLASSROOM," WITH EMPHASIS UPON THE FLEXIBILITY AND DIVERSITY OF THE PROGRAM. THE APPENDIX PROVIDES DESCRIPTIONS OF VARIOUS PROJECT MATERIALS. (DH)

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# Harvard Project Physics Progress Report

SE 003 861

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Harvard Project Physics

# PROJECT PHYSICS : A REPORT ON ITS AIMS AND PROGRESS

(DRAFT OF TALK AT AAPT MEETING, 1 FEBRUARY 1967)

by Gerald Holton

## INTRODUCTION

This is a progress report on a serious experiment in curriculum development which has involved so far about 80 physicists, teachers, film makers, experts on testing and so forth. We have been collaborating at Harvard Project Physics to produce a one-year course in physics for use in high schools and junior colleges. In 1962 we began a feasibility study with funds from the Carnegie Corporation and the Sloan Foundation, and in June 1964 started work on a larger scale with federal funds, first from the Office of Education and later also from the National Science Foundation.

The current version of materials is now being tried out with 2,600 students on a controlled experimental basis. After further revisions, we plan a thorough trial involving about one hundred schools next year, nearly half of them actually drawn at random and induced to give Project Physics a try. By late 1968 or early in 1969 we hope to have available not only most of the tested course materials, but also a thorough evaluation report based on the experience of the final test year.

We have been working hard and have learned much; from the beginning we planned on writing and testing and re-writing the materials every year during the four year cycle, so we have been able to change our minds even on quite fundamental things in the light of feedback from our classes, and this process will continue for a year or so. This freedom to work carefully and under classic conditions of experimentation, so familiar in physics itself, has been very precious to all of us. Because in a laboratory situation one should wait for results before one goes public and because we have only about half the funds we could wisely be using in this work, we have, until this winter, kept as silent as the world allows, and have concentrated on giving detailed and frequent briefings for those who actually work with the Project or those (such as the Regional Counselors of the AIP, the almost daily visitors from abroad, etc.) who have expressed an interest in early collaboration.

But now the time has come to give a progress report to our colleagues; we have some ideas and questions to share with you, and we will tell you something of the vision we have for this course development in particular, and indeed for the course of curriculum development in general.

Our progress report is based on preliminary data—16 schools last year, 54 this year (see map, Fig. 1). Our main aim today is to inform you of our work and to invite your collaboration in bringing this Project to a successful conclusion and into widest classroom use.

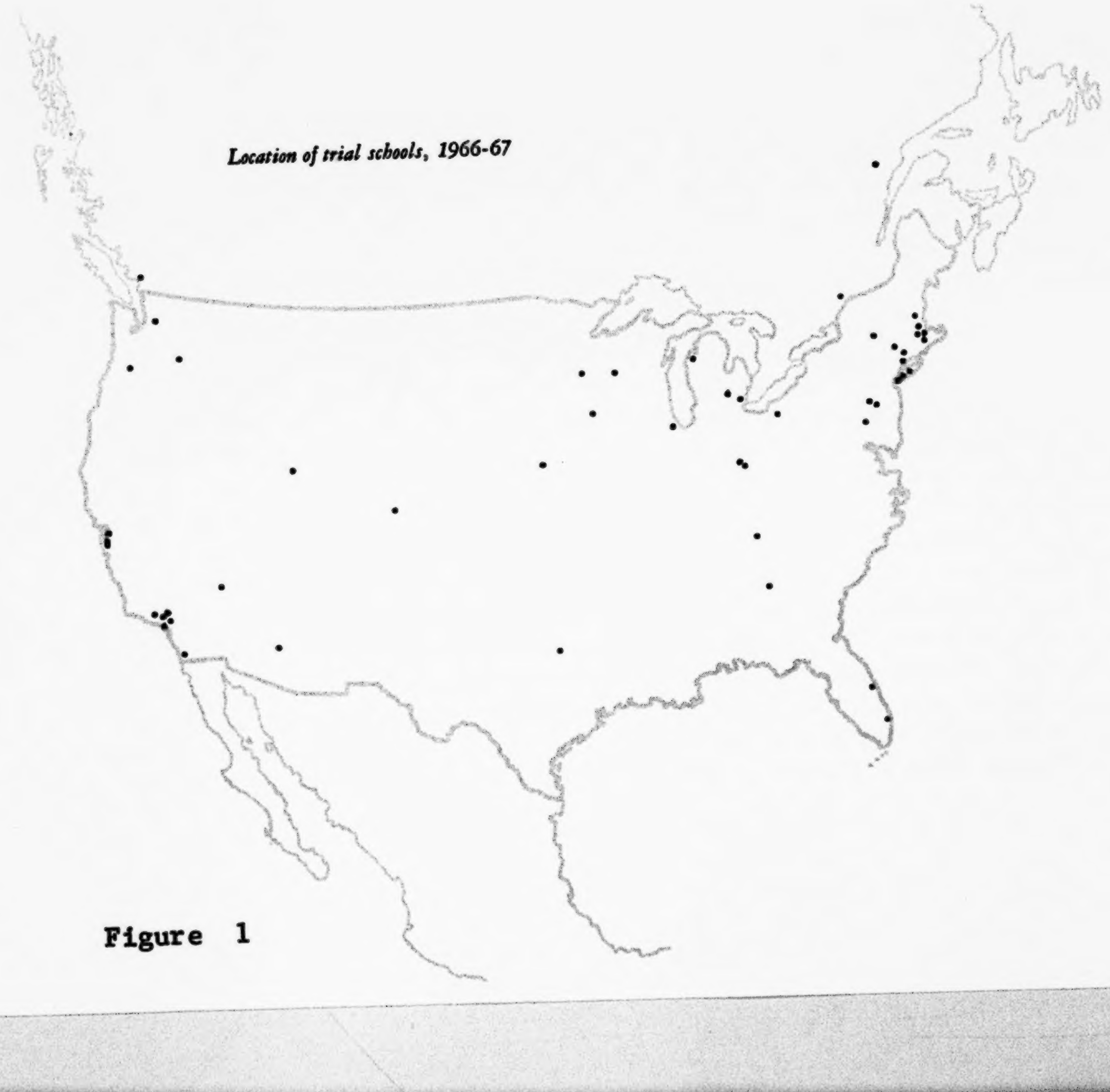

**Figure 1**

## PARTICIPATING SCHOOLS, OR SCHOOL DISTRICTS, 1966-67

West High School
Phoenix, Arizona

Berkeley High School
Berkeley, California

Claremont High School
Claremont, California

Laguna Beach High School
Laguna Beach, California

Los Altos High School
Los Altos, California

The Thacher School
Ojai, California

Henry M. Gunn Senior High School
Palo Alto, California

Capuchino High School
San Bruno, California

San Diego High School
San Diego, California

Clairmont High School
San Diego, California

Santa Fe High School
Santa Fe Springs, California

Lowell High School
Whittier, California

Wheat Ridge High School
Wheat Ridge, Colorado

Staples High School
Westport, Connecticut

The Loomis School
Windsor, Connecticut

Nova High School
Fort Lauderdale, Florida

Melbourne High School
Melbourne, Florida

Fulton High School
Atlanta, Georgia

Senn High School
Chicago, Illinois

Osage Community Schools
Osage, Iowa

Catholic High School of Baltimore
Baltimore, Maryland

Lansdowne Senior High School
Baltimore, Maryland

Burlington High School
Burlington, Massachusetts

Canton High School
Canton, Massachusetts

Dorchester High School
Dorchester, Massachusetts

Simon's Rock
Great Barrington, Massachusetts

Newton South High School
Newton Centre, Massachusetts

Henry Ford High School
Detroit, Michigan

Interlochen Arts Academy
Interlochen, Michigan

J.W. Sexton High School
Lansing, Michigan

Convent of the Visitation
Saint Paul, Minnesota

Omaha Benson High School
Omaha, Nebraska

Valley High School
Las Vegas, Nevada

Phillips Exeter Academy
Exeter, New Hampshire

Brooklyn Technical High School
Brooklyn, New York

Burnt-Hills-Ballston Lake Central Schools
Burnt Hills, New York

Mater Christi Diocesan High School
Long Island City, New York

Paul D. Schreiber High School
Port Washington, New York

Princeton High School
Cincinnati, Ohio

Talawanda High School
Oxford, Ohio

Solon High School
Solon, Ohio

Grant High School
Portland, Oregon

South Philadelphia High School
Phiadelphia, Pennsylvania

Plymouth-Whitemarsh Joint School System
Plymouth Meeting, Pennsylvania

Oak Ridge High School
Oak Ridge, Tennessee

St. Mark's School of Texas
Dallas, Texas

Logan High School
Logan, Utah

Kennewick Senior High School
Kennewick, Washington

Mercer Island Senior High School
Mercer Island, Washington

Rice Lake High School
Wisconsin

West Vancouver Secondary School
West Vancouver, B.C., Canada

John Rennie High School
Pointe Claire, P.Q., Canada

Menntaskolinn Ad
Laugarvatni, Iceland

## PARTICIPANTS IN HARVARD PROJECT PHYSICS

In terms of actual participants so far, either full-time while on leave at Harvard University or as consultants, the list of names is long and distinguished. So is the Advisory Committee of the Project*. The distribution of fields represented is symbolic of our decision from the beginning to draw from a great variety of fields and competences. In addition to physicists and high school teachers, you find chemists, historians of science, philosophers of science, science educators and experts interested in publishing, and in scientific manpower problems. In all our planning and work, from the very beginning, we have intentionally built on the broadest possible base. Here again the unique arrangement of having three co-directors is significant: I am a physicist who is also working in the history of science; Professor Fletcher Watson of the Harvard Graduate School of Education is a science educator who has also done professional work as an astronomer, and Dr. James Rutherford of the faculty of the Harvard Graduate School of Education is a former high school teacher and our superb administrator, ever sensitive to the day-to-day needs and possibilities of the classroom. This triumvirate arrangement has allowed us to keep in working contact with a whole range of professions from the very beginning.

We now have a long list of materials in various stages of accomplishment or design of which the other speakers, with a little overlap, will tell some details. Other details will be found in the newsletters we have released from time to time, and are free on request by writing to the following address: Newsletter Editor, Harvard Project Physics, Pierce Hall, Harvard University, Cambridge, Mass. 02138. The fact that over 18,000 have written in to put themselves on the mailing list indicates something of the interest we have encountered.

---

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Columbia University

Leonard K. Nash
Harvard

I. I. Rabi
Columbia University

## SURVEY OF AIMS AND CONTENTS

A wealth of material has been produced by the Project so far; most of it has been tested and revised at least once. The relationship between the different parts and the different media is expressed symbolically in Fig. 2 in which are displayed examples of the components which make up Unit 1, Concepts of Motion , the first of the basic six units of the course. Dr. Rutherford and others later this afternoon will speak in more detail about all of these components.

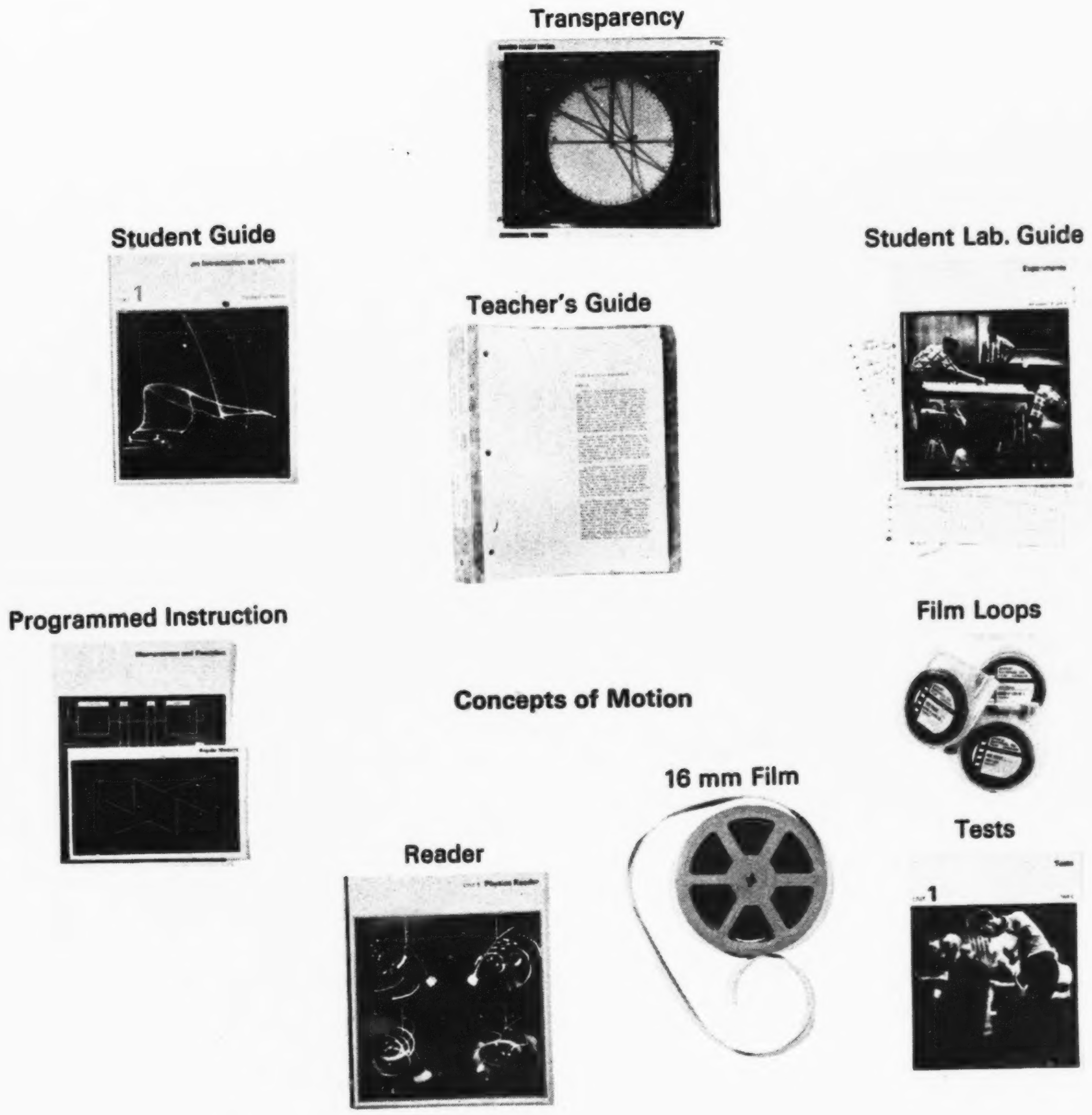
Transparency
Student Guide
Student Lab. Guide
Teacher's Guide
Programmed Instruction
Film Loops
Concepts of Motion
16 mm Film
Tests
Reader

Figure 2

We have divided the course material into six basic units, each of which is to be conceived as a set of materials of the same kind as shown here (Fig. 2) for the first of these units, and each of which is meant to occupy the average class from one to two months. Consequently, we have produced six "texts" or student guides, of four chapters each; six teacher guides with very extensive discussion of all the materials, laboratories, additional background in physics or history of science and the like, a day-to-day program for those teachers who prefer to teach in that way, and the usual other details which teachers have every right to expect to be furnished to them.

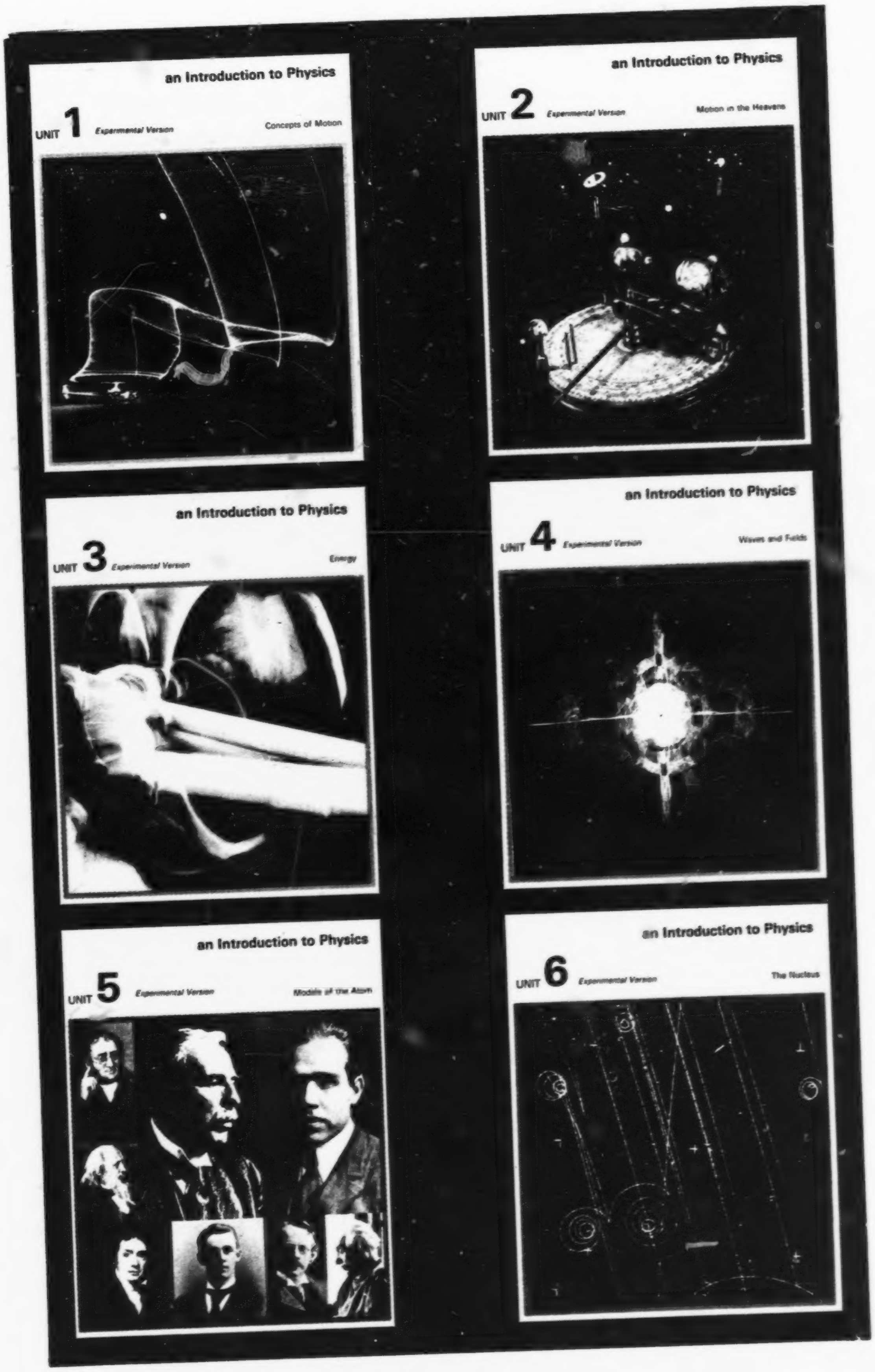
an Introduction to Physics
UNIT 1 Experimental Version
Concepts of Motion
an Introduction to Physics
UNIT 2 Experimental Version
Motion in the Heavens
an Introduction to Physics
UNIT 3 Experimental Version
Energy
an Introduction to Physics
UNIT 4 Experimental Version
Waves and Fields
an Introduction to Physics
UNIT 5 Experimental Version
Models of the Atom
an Introduction to Physics
UNIT 6 Experimental Version
The Nucleus

Figure 3

Now the topic I particularly wish to discuss this afternoon is the material content of the course and the aims and objectives of the course. These belong together because the material content reflects the aims and objectives.

If I were to select from the many aims and objectives which urge themselves on any curriculum maker today, I would put at the head of the list these four: to make a coherent, tested course for use on a national scale alongside the others that have been developed previously, but accentuating those aspects of physics and pedagogy which are widely held to be desirable and so far have not been prominently dealt with in course developments in physics on the high school level. We can hope, in this way, to provide variety in the physics teacher's arsenal, instead of becoming merely imitative.

Second, we hope to do our share to help stem to some degree the decline in proportionate enrollment in physics at the high school level—a decline which in fact is now reaching into the college years. Professor Watson will examine this problem in some detail.

Third, but by no means lower in priority than the other aims, is the obvious and necessary decision to provide teachers with all the necessary aids for teaching good physics in realistic classroom situations as they now exist and are likely to continue—and good physics defined in the widest, humanistic way possible, rather than in pre-professional terms alone. Professor Rutherford will discuss some of the ways we have tried to meet this goal.

Fourth, our course development required thinking entirely anew through some quite basic questions, such as the new role of the teacher and his involvement with the class, the new desire to allow greater diversity and flexibility, and the new opportunities opened up by the developing technology of education. Therefore, we have been evolving new guide lines that may help curriculum development in general in this country. Let us examine these aims in more detail to see how it can help us decide on the structure and content of the course.

## A NEW EMPHASIS

What kind of an alternative physics course should be available to students? Here I agree strongly with I. I. Rabi, one of the members of our Advisory Committee, who has said that physics now lies at the "core of the humanistic education of our time." This does not have to mean a "soft" physics course or a course that does poetry instead of physics. On the contrary, it can mean a physics course that accentuates just those elements which characterize the most thoughtful and fundamental achievements in physics itself, from Newton to Bohr. Indeed, this aim is along the same line as that expressed by a committee of the Pre-college Physics Project of the American Institute of Physics, which recommended that more than one type of physics course should be available in schools; the second suggested course, they wrote, "would not be a regular physics course, watered down or dressed up, but rather a serious course, thoughtfully designed to fill the needs of today's educated citizen, for whom this may be the only physics course in his educational experience."

During the past three or four years, articles, editorials and letters to the editor in journals such as *Physics Today*, and *The Physics Teacher*, have indicated that many people support Professor Rabi's request that good physics on the introductory level should be physics taught from a humanistic point of view. This opinion is shared not only by physicists but it also coincides precisely with the expressed interests of physics teachers themselves. Thus, in *The Physics Teacher* of March, 1965, a survey reported the replies of 1,382 high school physics teachers. Seventy-nine per cent thought that high school students stay away from physics because in their schools the course as now given is too difficult to suit their abilities and desires, and yet 91 per cent said also that a physics course with a cultural component is needed by nearly everyone.

## SURVEY OF COURSE CONTENT

As I indicated, high on the list of aims must of course be a desire to teach "good physics" or, as it is sometimes phrased, "what physicists would recognize as good physics," to give this phrase an operational meaning. But this laudable aim can be a trap, if the goal is not faced realistically. I often think of the father of a student in one of our trial schools who came in with a set of *Physical Review* issues; working as a physicist in a government laboratory, he thought the students in his daughter's class should get "the real stuff." The fact is, of course, that the pyramidal structure of physics, so beautiful and almost unique to our field, makes it practically impossible to talk in honest detail about the actual problems which physicists are now working on, or interested in, at least in an introductory course for the average student in high school, or for that matter in college. Therefore, except for rare and specially prepared cases, "good physics" in high school cannot be the details of contemporary work.

But even a piece of older knowledge that is recognized as good physics by physicists would, in most instances, require a major effort, perhaps many months, to get the story right—for example, why the sky is blue, why conductors sometimes obey Ohm's Law, why solid bodies sometimes obey Hooke's Law, why water freezes. These are good questions, and they are often asked at Ph.D. oral examinations. We have not wanted to deal with a catalogue of well established items and pieces, because we believe they neither tell a coherent story, nor can, in fact, allow us to do justice to them in the time available without diluting the physics considerably; and this, above all, we do not want to do.

Nor do we want to go down another road which used to be more fashionable many years ago than it is now—namely to find those few pieces of physics which in fact can be presented in a complete and self-contained and correct way. This desire has misled many of the old books to present physics as a disconnected set of little pieces, typological lists, and idealized cases that have no other merit than allowing the teacher to keep closed the doors to the real difficulties. This was the era of physics courses in which Atwood's machine, Wheatstone Bridges, Archimedes' principle and the lens equation were triumphant—the lowest common denominator which still turns up all too frequently in national tests. If a student has studied this sort of thing so well that he can answer all the obvious questions at the end of the course, and if in this pursuit he has seen none of what is sometimes called the general education aspect or humanistic aspect of physics, namely the sweeping power of a few fundamental laws, the use and limit of models in physics, the use and limit of mathematical formulations, the beautiful and sometimes awesome story of how real people made physics, the persistence of great themes, such as atomism, in the face of continual disproof of older models—in short, if he has not seen the characteristics of physics which have given this subject its centrality, both in science and in the history of ideas—then, we must conclude, he has not begun to see what physics is all about. If he is, by any chance, nevertheless attracted to physics by the good old list of pulleys and trolleys and LCR circuits, he is entering his study under a grave misapprehension. Good physics is not "one damn thing after another," not even one beautiful piece of physics after another. Rather it has a continuous inherent story line, a sequence of related ideas whose pursuit provides one with the cumulative effect of an even higher vantage point and more encompassing view of the workings of nature.

When seen in this way, physics must be presented not only as a science with interesting concepts and predictive powers, but also a science which has peculiarly and perhaps uniquely a structure that connects these concepts; and in addition, to some extent, one wants to show the student occasionally the cultural roots and humanistic consequences of the science which, in most instances, will touch and concern them only in this way.

Thus you will see something of the framework of our efforts. Now to more specific details concerning the contents of the units. Unit 1, Concepts of Motion, has four chapters: The Language of Motion, Free Fall, Some Complex Motions, and The Birth of Dynamics-Newton Explains Motion. The main theme is how to describe, and therefore know a lot, while being practically completely ignorant of details—possibly the most successful trick which physicists have devised. Now this material is, of course, proverbially difficult for beginning students, and the course would be rather pedestrian if it only tried to drill the use of some conceptual tools, such as the intuitive concept of instantaneous velocity, the use of vectors, etc. But here we have a chance to let students learn about motion not merely by launching rockets and using air tracks and computing periods of lunar satellites, but also we need not pass up the chance to repeat the experiments which Galileo so lovingly described. By reading his own eloquent words, and using his techniques, one can get a sense of the development of ideas, and the realization that science always changes and sometimes comes to important turning points. And perhaps this is an occasion for arguing whether Galileo could really have done what he said he did with the experimental accuracy he claimed.

It is for many students also a time to discover, as the Prologue of Unit 1 expresses, "For the time being, we shall have to set aside most of the more complex and interesting questions which one would also like to be able to answer; questions about colors and textures of things, their warmth and life, how systems exchange energy and information, and how we grow and think. These more complex features the physical scientist, as much as anyone else, eventually wants to understand; but we cannot usefully start with them...So, to begin with, we shall concentrate on a selected group of questions: not questions about events of all kinds whatever, but only questions about the motion of solid bodies, going on at the familiar man-sized scale. Not even all such motion, but only at first certain, particularly simple kinds."

The frequent use by the student of stroboscopic photographs he makes of moving objects in this unit, is, in many ways, a rather symbolic exercise: from "observations" he can obtain first the description of motion and then an explanation in terms of forces. With this technique and instrument, the complex situation is narrowed down to essential pinpoints of light, and after this abstraction a further abstraction becomes possible, that of playing out the events in the world of mathematics. After that we can return to the world of real bodies, which we now can master so much better with the concepts of kinematics and dynamics.

Unit 2 applies what Unit 1 has prepared for. It is entitled Motion in the Heavens, and deals with the dynamics of our planetary system. But in this unit we can do what in other units we have not so much time for: namely, set the achievement of an understanding of the motions in our planetary system in its historic context, as well as raising such methodological questions as how one is to decide between rival theories. Therefore, the chapter headings of Unit 2 are as follows: Where is the Earth?—The Greek Answers. Does The Earth Move?—The Work of Copernicus and Tycho. A New Universe Appears—The Work of Kepler and Galileo. The Unity of Earth and Sky—The Work of Newton.

At the end of this unit, particularly through the Reader, the student can go beyond the scientific aspect of the Newtonian synthesis. Newton's work helped to bring a wholly new sense of intellectual possibilities into the age which he shaped. The mind of man now seems capable of understanding all things in heaven and earth. To a degree, what we think today and how we run our affairs is still based on these events of three centuries ago. And to a degree the physics of today will do the same for future times. We therefore suggest to the student that if he understands the way in which science influences some one chosen part of history, he shall be better prepared to understand how the science of yesterday and today influences the world in which he lives.

After the intellectual reach into the sky in Unit 2, Unit 3 is the triumph of the mechanistic, Newtonian point of view throughout physics: the laws of conservation of mass and momentum; mechanical energy and the first law of thermodynamics (with the second law to be treated only qualitatively); kinetic theory, with some explicit attention to mention the power and limits of the model, and the new theme of our ability to master chaos; finally, going further from the discussion of two-body problems to many-body problems, a chapter on mechanical waves.

A number of themes can be touched upon in addition to the rather obvious ones. One is symmetry, both the spatial and the temporal aspects. Another is the connection between science and technology. In discussing the laws of thermodynamics, there we can grab the chance to make the point (in not many pages of student guide and in the reading) that the heat engine, like many other technical by-products of scientific work, is not a device operating in a vacuum of social consequences. Rather, the heat engine helped to alter the structure of Western society during the Industrial Revolution, and affected the imagination of poets and theologians no less than of mathematicians.

We are now ready for the treatment of electricity, magnetism, and light—in short, the failure of the mechanistic view and a new physics. This is the subject of Unit 4, which deals with fields at rest, fields in motion, and light, as in electromagnetic wave phenomenon. Professor Mara will speak further on the structure of Units 3 and 4 as they are now being revised.

Unit 5 deals with the models of the atom: The chemical basis of atomic theory; electrons and quanta; the Rutherford-Bohr model of the atom; and some introduction to subsequent theories, particularly wave-particle dualism.

Unit 6 is on the nucleus: Radioactivity; isotopes; the nucleus and elementary particles; nuclear energy and nuclear forces.

Again from time to time in all these units, whether in the student guide or in the Reader or through the teacher's guide, occasions are shown where the connection between physics and other sciences and between science and other endeavors can be pointed out. And this, of course, only being true to the real state of affairs. Physics by itself, without ties to anything else, is an invention of its most hostile foes and its most single-minded protagonists. One cannot survive a single day in a real physics laboratory on physics alone. One needs mathematics and chemistry and metallurgy and technology, —and indeed the commitment of society as a whole....a point about which physicists are bound to begin to wonder more and more as time goes on if present indications are true.

These six units make up the *basic* or main line course which most teachers, certainly after the initial period of use, will begin to supplement by means of one or more *supplemental units.* We have made a start on six such supplemental units, and hope for a total of some twenty, from which the teacher can choose freely on condition that he has fully and thoroughly covered the material in the six basic units. This combination of providing a manageable basic course and yet have up to one-third of additional material in full control of the teacher's own choice (which, incidentally, may be different materials for different members of the class) yields a model in which the decisions are far more teacher-centered than has sometimes been the case. Dr. Rutherford will speak further on this most essential point.

## UNIT ONE: CONCEPTS OF MOTION

Student Guide (Experimental Version, 1966)

### PROLOGUE

### CHAPTER 1: THE LANGUAGE OF MOTION: POSITION, SPEED, ACCELERATION

In nature, motion is everywhere
From nature into the laboratory
Uniform straight-line motion
Specifying position
A definition of uniform speed
Graphing motion
The concept of average speed during nonuniform motion
The concept of instantaneous speed during nonuniform motion
Acceleration

### CHAPTER 2: FREE FALL—GALILEO DESCRIBES MOTION

The Aristotelian theory of motion
Galileo and his times
Galileo's Two New Sciences
Why study the motion of freely falling bodies
A definition of uniform acceleration
Galileo's hypothesis cannot be tested directly
Looking for logical consequences of Galileo's hypothesis
Galileo turns to an indirect test
How valid was Galileo's procedure
What is the magnitude of the acceleration of freely falling bodies

### CHAPTER 3: SOME COMPLEX MOTIONS

What are complex motions
The question of direction: vectors
Projectile motion
The superposition principle
What is the path of a projectile
Galilean relativity
Circular motion
Describing uniform circular motion
Centripetal acceleration
The geometric relationship between velocity and acceleration
The magnitude of centripetal acceleration
The motion of earth satellites
What about other complex motions

### CHAPTER 4: THE BIRTH OF DYNAMICS—NEWTON EXPLAINS MOTION

The beginning of dynamics
Explanation and the laws of motion
The first law: the concept of force appears
The Aristotelian view
The principle of inertia
The significance of the first law of motion
The second law of motion
Testing the second law of motion
Units of mass and force
Using the second law to explain motion
Gravitation and the second law
Newton's third law
The third law and interacting objects
The unity of the three laws

### EPILOGUE

# UNIT TWO: MOTION IN THE HEAVENS

## PROLOGUE

## CHAPTER 5: WHERE IS THE EARTH?—THE GREEKS' ANSWERS

- Motions of the sun and stars
- Motions of the moon
- The wandering stars
- Plato's problem
- A first solution
- A sun-centered solution
- The geocentric system of Ptolemy

## CHAPTER 6: DOES THE EARTH MOVE?—THE WORKS OF COPERNICUS AND TYCHO

- The Copernican system
- New conclusions
- Arguments for the Copernican system
- Arguments against the Copernican System
- Historic consequences
- Judging a theory
- Tycho Brahe
- Tycho's observations
- Tycho's compromise system

## CHAPTER 7: A NEW UNIVERSE APPEARS—THE WORK OF KEPLER AND GALILEO

- The abandonment of uniform circular motion
- Kepler's second law
- Kepler's first law
- Using the first two laws
- Kepler's third law
- The new concept of physical law
- Galileo's viewpoint
- The telescopic evidence
- Galileo's arguments
- The opposition to Galileo
- Science and freedom

## CHAPTER 8: THE UNITY OF EARTH AND SKY—THE WORK OF NEWTON

- Introduction
- A sketch of Newton's life
- Newton's _Principia_
- A preview of Newton's analysis
- Motion under a central force
- The inverse-square law of planetary force
- Law of Universal Gravitation
- The magnitude of planetary force
- Testing a general law
- The moon and universal gravitation
- Gravitation and planetary motion
- The scope of the principle of universal gravitation
- The moon's irregular motion
- The tides
- Comets
- Relative masses of planets and the sun
- The actual mass of celestial bodies
- Beyond the solar system
- Gravitational fields
- Some influences on Newton's work
- Newton's place in modern science

## UNIT THREE: ENERGY

Student Guide (Experimental Version, 1966)

### PROLOGUE

### CHAPTER 9: THE CONSERVATION OF MASS

Conservation laws
Is weight conserved?
Distinction between weight and mass
Is mass really conserved?

### CHAPTER 10: THE CONSERVATION OF MOMENTUM AND MECHANICAL ENERGY

Conservation of momentum
Views of Descartes and Newton on the quantity of motion in the world
Kinetic and potential energy
Leibniz and the principle of conservation of energy
Internal energy and heat
Work and energy
Forces that don't do any work
Summary of the principles of mechanics

### CHAPTER 11: HEAT AND WORK

Heat and work
The Savery and Newcomen engines
Improvements and applications of steam engines
The Industrial Revolution and its social and cultural effects
Measuring the performance of steam engines
The discovery of the law of conservation of energy
Energy in biological systems
The Second Law of Thermodynamics and the dissipation of energy

### CHAPTER 12: A GAS AS A MECHANICAL SYSTEM

Explanations based on the motions of small invisible particles
Air pressure
The Boyle-Newton theory of gas pressure
Daniel Bernoulli and the kinetic theory of gases
The ideal gas law
Heat and molecular kinetic energy
Expansion into a vacuum and the mechanical equivalent of heat
Making the kinetic theory more realistic
Distribution of molecular speeds and fluctuations
Molecular magnitudes
The dissipation of energy and Maxwell's demon
Criticisms of kinetic theory based on the reversibility and recurrence paradoxes

### EPILOGUE

## UNIT FOUR: FIELDS AND WAVES

Student Guide (Experimental Version, 1966)

### PROLOGUE

### CHAPTER 13: CHARGES AND CURRENTS

The curious properties of lodestone and amber
Some electrostatic experiments
Magnetic and electrical force laws
Electrical currents
Currents act on magnets
Magnetism is an electrical effect

### CHAPTER 14: FIELDS

The concept of "field"
Representing gravity as a force field
Electric force fields
Adding fields
Mapping force fields
The concept of a "potential" field
Electric potential
Electric potential difference and current
Electric potential difference and power
Mapping potential fields
Magnetic fields
The path of a charged body in a magnetic field

### CHAPTER 15: WAVES

Introduction
What are waves?
The speed of propagation
Energy transport and communication
The superposition principle
Reflection
Periodic waves
Refraction
Interference patterns
Diffraction
Standing waves

### CHAPTER 16: ELECTROMAGNETISM AND LIGHT

Introduction: review and preview
Oersted and the discovery of electromagnetism
Quantitative studies of the magnetic effects of electric currents
Faraday and the magnetic induction of electric current
Maxwell's Electromagnetic Theory
Some properties of light
The particle and wave theories of light
The triumph of the wave theory of light in the nineteenth century
Light and the electromagnetic spectrum
The Ether—a serious problem

### EPILOGUE

## UNIT FIVE: MODELS OF THE ATOM

Student Guide (Experimental Version, 1966)

PROLOGUE

### CHAPTER 17: THE CHEMICAL BASIS OF ATOMIC THEORY

Dalton's atomic theory and the laws of chemical combination
The atomic masses of the elements
Other properties of the elements: valence
The search for order and regularity among the elements
Mendeleev's periodic table of the elements
The modern periodic table
Electricity and matter: qualitative studies
Electricity and matter: quantitative studies

### CHAPTER 18: ELECTRONS AND QUANTA

The problem of atomic structure: pieces of atoms
Cathode rays
The measurement of the charge of the electron: Millikan's experiment
The photoelectric effect
Einstein's theory of the photoelectric effect: quanta
X rays
Electrons, quanta and the atom

### CHAPTER 19: THE RUTHERFORD-BOHR MODEL OF THE ATOM

Spectra of gases
Rutherford's nuclear model of the atom
Nuclear charge and size
The Bohr theory: the postulates
The Bohr theory: the spectral series of hydrogen
Stationary state of atoms: the Franck-Hertz experiment
The periodic table of the elements
The failure of the Bohr theory and the state of atomic theory in the early 1920's

### CHAPTER 20: MODERN PHYSICAL THEORIES

The special relativity theory of Einstein
The Compton effect and the wave-particle dualism of radiation
DeBroglie's hypothesis and the dual nature of matter
Quantum mechanics
Wave-particle dualism and the uncertainty principle
Wave-particle dualism and probability

EPILOGUE

APPENDIX

# UNIT SIX: THE NUCLEUS

## PROLOGUE

## CHAPTER 21: RADIOACTIVITY

- Becquerel's discovery
- Other radioactive elements are discovered
- The properties and nature of the radiations: α, β, γ
- Radioactive transformations
- Decay constant; activity, half-life

## CHAPTER 22: ISOTOPES

- The concept of isotopes; the displacement rules
- The mass-spectrographic separation of isotopes
- The stable isotopes of the elements and their relative abundance
- Atomic masses

## CHAPTER 23: THE NUCLEUS

- The problem of the composition and structure of the atomic nucleus
- The proton-electron hypothesis of nuclear structure
- The discovery of artificial transmutation
- The discovery of the neutron
- The proton-neutron theory of the composition of atomic nuclei
- The need for particle accelerators
- Nuclear reactions
- Artificially induced radioactivity

## CHAPTER 24: NUCLEAR ENERGY; NUCLEAR FORCES

- Conservation of energy in nuclear reactions
- Energy of nuclear binding
- The mass-energy balance in nuclear reactions
- Nuclear fission: its discovery
- Nuclear fission: practical applications
- Nuclear fusion
- Nuclear forces and nuclear models
- Biological and medical applications of nuclear physics

## EPILOGUE

## TITLES OF PROPOSED SUPPLEMENTAL UNITS

ACCELERATORS AND REACTORS
SPECIAL RELATIVITY
THERMAL MOTION
ASTRONAUTICS AND "SPACE" PHYSICS
PARTICLE PHYSICS
DISCOVERY IN THE PHYSICAL SCIENCES
BIOPHYSICS
COSMOGONY
THE PHYSICS OF EVERYDAY OPTICS
DIFFRACTION: OBSERVING THE WORLD THROUGH SMALL OPENINGS
CHEMISTRY AND PHYSICS
RADIOISOTOPES AND THEIR APPLICATIONS
SOCIAL CONSEQUENCES OF SCIENTIFIC TECHNOLOGY
PHYSICS AND ENGINEERING
THE PHYSICS OF TRANSPORTATION
THE PHYSICS OF MUSIC
THE PHYSICS OF CRYSTALS
PHYSICS AND ELECTRONICS
PHYSICS AND SPORTS
SCIENCE AND LITERATURE
THE EYE
THE EAR
PHYSICS FOR THE AIRPLANE PASSENGER

## PRINCIPLES OF SELECTION

I stressed that the content of the basic units is carefully monitored to narrow down on the most basic materials and the list given shows that about one-third of the content refers to twentieth century concepts, this fraction can be increased two-thirds with proper choice of supplemental units. I should say a word about the selection principles which we have been using for making these decisions on content. Such principles have been laid down and reaffirmed repeatedly for physics courses, starting with the Carleton Conference of the AAPT nine years ago, and there is not much disagreement in the profession concerning the list of fundamental ideas and theories. Despite the infinite proliferation of detail, the basic physics remains manageable in a one-year course (although, of course, it would be far better to have more than one year). The main concepts I listed in discussing the Units is a list that follows closely along the lines adopted at the Carleton Conference, at the Boulder Conference of 1964, and on other occasions, and which is incorporated in a number of existing and well-regarded textbooks of introductory physics.

We have made some efforts to assure that any concept or theme of physics that enters the course in its final form will, in fact, be needed either in preparing for the understanding of a later part of the course or because the concept or theme is one so significant that it makes an appearance repeatedly. The use of modular concepts in physics is of course one of the trademarks of our science. For example, the ideas of projectile motion turn up in Unit 1, first in kinematics and then in dynamics, again in Unit 2 (for example, in the calculation of the fall of the moon from its inertial motion); again in Unit 3 in treating the conservation laws, again in Units 4 and 5 in connection with $\frac{e}{m}$ measurements and mass-spectographs, and it certainly should turn up again in Unit 6 where we have a chance to speak about the design of the linear accelerator, which has to take into account the fall of the electron during its two mile trajectory.

One must continually guard against bad habits, such as reverting to "fascinating" encyclopaedic detail, or to material which is really too advanced for most students and teachers. We also must continually guard against the bad habits we learned in a book-oriented world, and must try to make proper use of other media, starting with the best possible illustrations and designs of the book materials themselves. We must remember that those who are deaf to physics may not be blind to physics, or may be kinesthetically sensitive to experience with laboratory equipment. Teaching ideas through only one medium, and preferably, through the printed word, is no longer sound, either pedagogically or technologically.

To put it bluntly, we must have the courage to say "no" to the pressures of pre-graduate-school professionalism, to those who will complain because they do not find their own specialization represented. We shall have to answer that each of the many physicists contributing to the course has carefully refrained from concentrating on the details of his own research field. The course must be up-to-date precisely by avoiding quickly obsolescent materials but attending to those concepts and ideas which are so basic that they are likely to be at the foundations of physics for a very long time in the future.

A word should also be said about the place of history of science in a course such as this. Nobody in the Project has favored either a strictly historical order, or using the history of science for its own sake. Rather, we have followed the precept that a physics course can use the history of science occasionally as a pedagogic aid without becoming itself a course in the history of physics. As is the case with the other non-physics materials, a little goes a long way. If I have stressed historical examples in the presentation today, it is because even this little is so much more than is usually found in an introductory course at the high school level.

## NEW DIRECTIONS FOR SCIENCE CURRICULA

I come now to the last on the list of four chief aims for our course. Just as important as producing a specific physics curriculum, and perhaps even more so in the long run, is our aim of helping to provide new guidelines for the direction of curriculum development in general for the late 1960's and the 1970's. It is, after all, high time for that! A whole decade has gone by since Sputnik helped spark a first round of curriculum development. Educationally speaking, this was a whole generation ago. That work was carried out in the ideological setting of that time, which was in many ways totally different from today's. We have, for example, a very different amount of knowledge and a different attitude about schools, teachers and students. Thus, we have begun to respect far more the role of teacher as collaborator in making curriculum development work in the classroom on his own terms, and we have become much more interested in considering the different needs of different students in the same classroom.

We have different assumptions of what is and is not feasible or desirable for schools to do. For example, we would not today set up a curriculum development that caters only to the intellectual needs of the student or to the intellectual elite. There is also now, happily, a rather different situation with respect to the availability of money for school equipment (it is larger by a factor of about 100) and of the participation of industry. We have also learned a lot in ten years about the limits of effectiveness of the hopes and dreams of curriculum makers, and one aspect of that is a new realization that a detailed scholarly evaluation of the achievement and limitations of the curriculum development under the various circumstances is a prime responsibility of the curriculum group, if not of an independent agency.

In short, the time has come for a new educational deal in the cooperation of schools, teachers, curriculum groups, sponsoring agencies, industry, and teacher-training institutions. While we feel deeply indebted to the pioneering work in curriculum development by such groups as BSCS, CHEM Study, CBA, and PSSC, we fully expect that Project Physics, the first of the new, second-generation curriculum developments for senior high school, can help to indicate the elements of this new deal.

We hope to show the way particularly in two respects, which have been implicit in my discussion, by refining and accentuating the role of the teacher; and by building into the system enough flexibility so that it can be a model for dealing with diversity.

The teachers we have been dealing with have in many cases been immensely ingenious. Several are with us all year in Cambridge, and 15 are working with us this summer. In addition, we have of course had continuous contact with teachers in the field. They are coming back for feedback conferences, they are being visited, and they keep in touch with us by mail practically every day on a well-regulated basis of feedback processing. They are doing a wonderful job in view of the almost brutal working conditions of high-school teaching generally.

But the profession as a whole is in great trouble, and college physicists should be really and actively concerned. As an AIP survey recently discovered, less than 10 per cent of the 17,000 high-school teachers who are in some physics class are occupied fully with the teaching of physics. Two-thirds of them "had fewer than the usual minimum of 18 college physics semester hours." This is far less than the average preparation of biology, chemistry, and mathematics teachers in the subjects which they teach. The rate of trained replacement for this group of 17,000 is shockingly low; about 500 new persons are prepared to teach physics each year, with about half of them having a B.S. in physics; but even of that small number, only about two-thirds actually do get employed as high school teachers. It stands to reason, at least as one conclusion, that we must make sure that any course which hopes to have a realistic chance of success will not approach the subject in a revolutionary, way-out fashion, which would require special teaching skills or extensive re-training of teachers.

We therefore find it encouraging that in our test schools the teachers almost unanimously agree that this approach allows them to teach sound physics in an exciting way—despite the incompleteness of the course at this stage of its development, and despite the fact that each teacher obliged himself to include at least one class of students of the kind that would not have been expected to sign up for the physics course as previously taught. Parenthetically, I should report that we have also surveyed our own students and find that a large majority responded positively to the course. Thus, to the question whether they were glad to have taken a physics course, the positive response was 79 per cent; 70 per cent said they would recommend taking a physics course to their friends; 63 per cent reported they found the course challenging and not too difficult at the level of their preparation; and 83 per cent singled out the laboratory experiments as being particularly enjoyable.

It is in our attempts to deal with diversity that we encounter a major new preoccupation in educational philosophy today; the preservation and exploitation of individual differences, both in teachers and in students. To assure individual involvement, the experience of teachers and students must allow for what the individual scientist takes for granted, namely variety, options, flexibility. Once alerted, you will discover that this is indeed a strong new message which is beginning to transform educational philosophy. For example, Patrick Suppes has recently written, "A body of evidence exists that attempts to show that children have different cognitive styles. For example, they may be either impulsive or reflective in their basic approach to learning. Indeed what we face is a fundamental question of educational philosophy: to what extent does society want to commit itself to accentuating differences in cognitive style by individualized techniques of teaching that cater to these differences?" The nineteenth century melting-pot philosophy of education said "no" to this possibility; I believe the next few decades will say "yes."

Already, among physicists, thoughtful people such as Walter Knight, Philip Morrison, and David Hawkins, have spoken eloquently on this point. Indeed, even a century ago, Maxwell expressed it excellently, when he said, "For the sake of persons of different types, scientific truth should be presented in different forms, and should be regarded as equally scientific, whether it appears in the robust form and vivid coloring of a physical illustration, or in the tenuity and paleness of a symbolic expression."

You will now see why, at the beginning, I asked for your help in this work. We have set ourselves a very large task. The group that has engaged itself to bring the work to a conclusion in the next year and a half will continue to need and make good use of advice and suggestions from all sides. In addition to the teacher training we are carrying on ourselves, we shall need the help of many colleagues for in-service, pre-service, and summer institute training opportunities for the teachers. In addition to our own film work, we hope for your collaboration if you have ideas that would fit into the course and have studio facilities accessible to you. In addition to our own laboratory group, we can add several development centers to those which have already identified themselves. The same applies to programmed instruction and to all the other components of our work. As physicists and educators, many of you have already been heavily involved in past efforts of curriculum improvement, and much has been done. We can be proud of it. But a great deal more remains to be done, and the burden falls on us again—there is no other group that will or can do the job. Let each of us who possibly can carry his share of the load.

And even more important than that, all of us in Project Physics, and particularly the teachers who always depend on their colleagues in the colleges and universities—all of us are banking on your continued moral support in our common goal to bring more students to the study of physics.

## Enrollments in public high school science by type of course and by sex, 1964-65

(Preliminary data)

Table 1

| Type of Course | Number of students enrolled, 1964-65 | | |
|---|---|---|---|
| | Boys | Girls | Total |
| General Science, Total | 1,143,000 | 1,032,900 | 2,175,900 |
| 9th grade gen. sci. | 1,087,400 | 990,000 | 2,077,400 |
| Advanced gen. sci. | 55,600 | 42,900 | 98,500 |
| Biology, Total | 1,333,400 | 1,361,000 | 2,694,400 |
| Traditional biol. (gr. 9) | 135,600 | 165,300 | 300,900 |
| Traditional biol. (gr. 10) | 974,900 | 961,000 | 1,935,900 |
| BSCS | 161,300 | 167,100 | 328,400 |
| Advanced biol. | 61,600 | 67,600 | 129,200 |
| Chemistry, Total | 606,100 | 478,500 | 1,084,600 |
| Traditional chemistry | 499,200 | 402,900 | 902,100 |
| CBA | 14,200 | 9,200 | 23,400 |
| CHEM study | 72,600 | 55,500 | 128,100 |
| Advanced chemistry | 20,100 | 10,900 | 31,000 |
| Physics, Total | 382,200 | 144,000 | 526,200 |
| Traditional physics | 281,800 | 102,900 | 384,700 |
| PSSC | 74,900 | 25,000 | 99,900 |
| Advanced physics | 25,500 | 16,100 | 41,600 |
| Physical Science | 167,000 | 123,700 | 290,700 |
| Earth-Space Science | 138,800 | 106,000 | 244,800 |
| Physiology | 6,400 | 7,700 | 14,100 |
| Research Science Seminar | 4,000 | 2,700 | 6,700 |
| All Other Sciences | 111,200 | 95,000 | 206,200 |
| Totals | 3,892,100 | 3,351,500 | 7,243,600 |

Released Nov. 1966 by National Center for Educational Statistics, Washington, D. C., through National Research Council.

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# WHY DO WE NEED MORE PHYSICS COURSES?

## (DRAFT OF TALK AT AAPT MEETING, 1 FEBRUARY 1967)

by Fletcher G. Watson

Why the schools need additional physics courses can be answered by looking both at the science enrollments in secondary schools and at the increasing importance of physics in our society. Preliminary figures on science enrollments in public secondary schools for 1964-65 have recently been made available by the U. S. Office of Education. From these figures we see that over 2.5 million students are taking a first course in biology, for the most part during their tenth or perhaps ninth grade in school. This enrollment is close to the total number of students in either of these grades. Put another way, biology is enrolling nearly all the students at one time or another.

Chemistry is currently enrolling just over a million in an introductory course. This figure is near forty per cent of the pupils who reach the eleventh or twelfth grades when chemistry is normally offered.

Physics is, however, enrolling just less than half a million in an introductory course, mostly in the twelfth grade. Most of these students have or will, also take chemistry. So we may conclude that perhaps forty per cent of the students are taking at least one course in the physical sciences. But each year over 2.5 million pupils are enrolled in the twelfth grade of public schools, and perhaps another quarter of a million are completing independent school, but we have no information about their programs of study. Then, of the 2.5 million completing public school, some 1.5 million per year will have elected no study in physical science, and some two million per year will have avoided physics.

Figure 1 shows how enrollments in these various science courses in secondary school have varied during recent years. Since we are primarily concerned with enrollments in physics, Fig. 2 shows the changing enrollments in comparison with the total pupils enrolled in grade twelve in public schools. As Table 2 shows, there has been a recent increase of about a hundred thousand in physics enrollments since 1962-63.

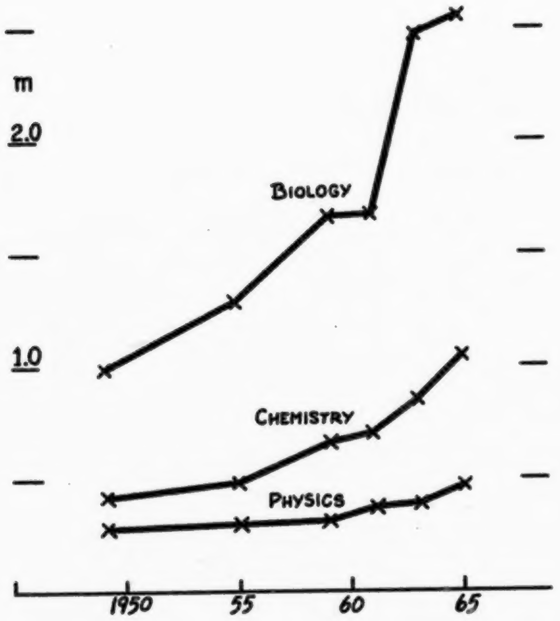

Figure 1

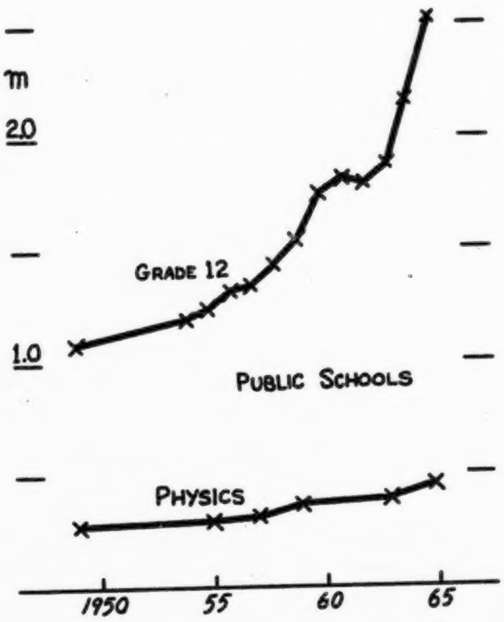

Figure 2

INTRODUCTORY PHYSICS ENROLLMENT - PUBLIC HIGH SCHOOLS

Table 2

| Year | No. taking Physics | Total # in 12th Grade | % of 12th Grade |
|---|---|---|---|
| 48-49 | 291,000 | 1,126,000** | 25.8 |
| 54-55 | 303,000 | 1,246,000 | 24.3 |
| 58-59 | 379,000 | 1,538,000 | 24.6 |
| 60-61 | 385,000 | 1,820,000 | 21.2 |
| 62-63* | 397,000 | 1,866,000 | 21.3 |
| 64-65** | 485,000 | 2,472,000 | 19.6 |

Sources: U.S. Office of Education, Digest of Educational Statistics 1965, for data on 1948-49 to 1962-63.

*U.S.O.E., published in Scientific Engineering Technical Manpower Comments, March 1966, p. 16.

**U.S.O.E., unpublished preliminary data, authorized for publication.

This is, however, explained by the increase of 600,000 students in grade twelve during the same interval.

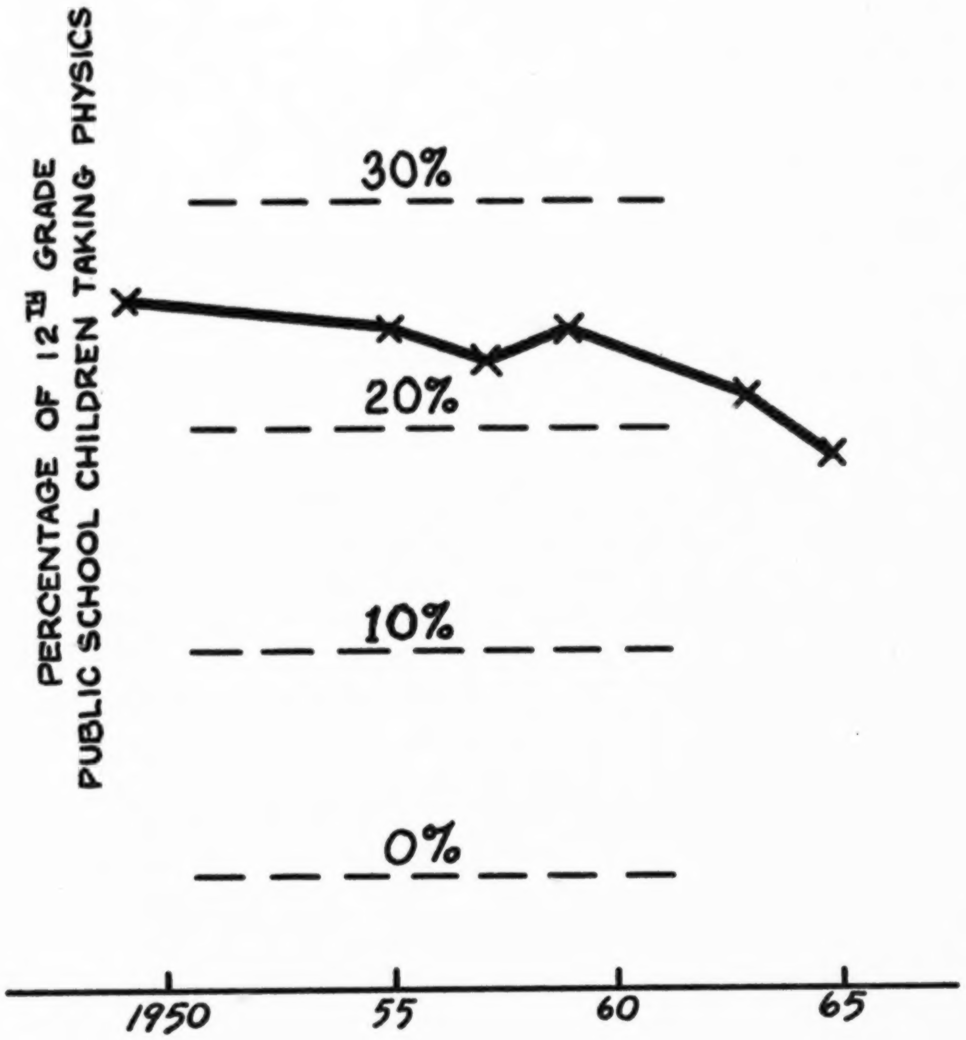

Figure 3

Figure 3 shows that since 1948-49 nationwide enrollment in introductory physics in secondary schools has declined at almost a steady rate. This leads to the sobering conclusion that an increasing, rather than decreasing, fraction of our children are completing secondary school without any systematic study of physics. At present four out of five high school graduates have taken no physics. Furthermore, very few of those who avoided physics in school will ever study physics in college. If we want any sizable segment of the population to have some introduction to physics, that study must be done in the secondary school.

Physics is a science through which young adults can begin to consider some basic questions about how we can attempt to explain the phenomena we observe. Also, throughout its long history physics has had profound effects on the philosophical orientation of Western culture. The individuals, instruments, assumptions, and expanding theories of physics provide an almost ideal vehicle through which young people can inspect science in the making, and engage to some extent in the same process. When applied to practical affairs, physics has been one of the major contributors to our ever advancing technology. For these, and other reason, we feel that physics should be studied by far more students. But if they are not enrolling in any of the current physics courses, what sort of course will attract them?

A large fraction of the students who avoid physics have interests which are strongly people-centered; that is, these students are interested in literature, history, art, music, languages, and all the humanities. These students are the prime target of Project Physics. In a rough diagram of interest in science versus general academic ability, the half million students now enrolling in physics will mostly be those of high scientific interest and high ability. Yet, physics does not even enroll all such students, for some are interested mainly in the biological sciences and do not see the desirability of studying physics. Our primary interest is, however, in the two million of less scientific interest and a wide range of academic ability. Certainly we are not so naive as to expect that any single course from Project Physics or any other group will be equally attractive to all

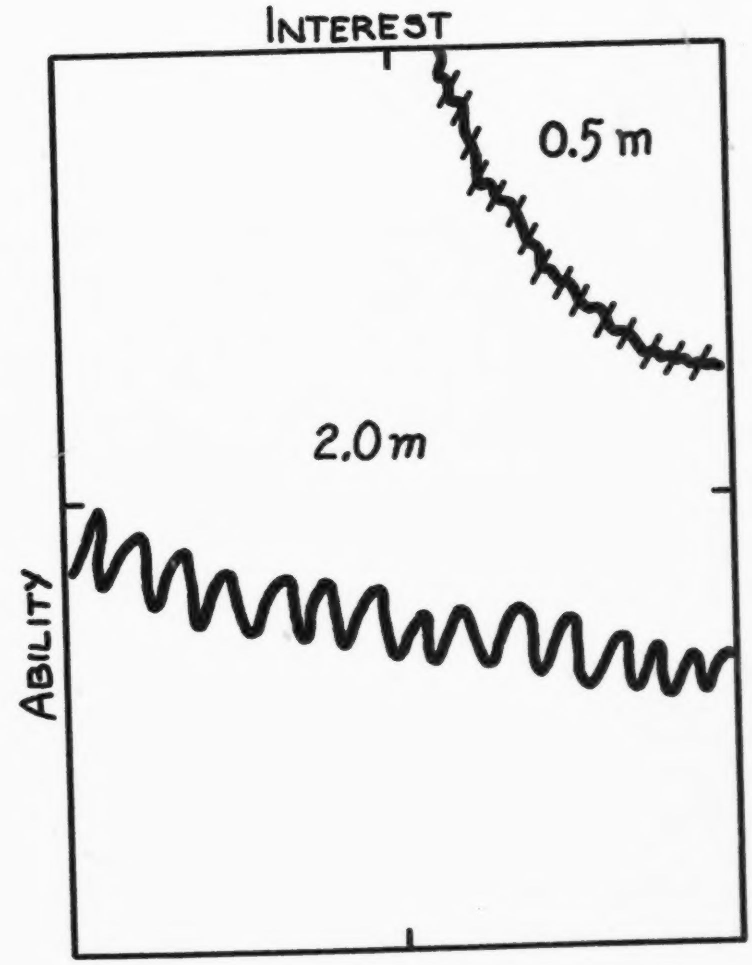

Figure 4

the current non-physics students. For example, some students are much interested in skills, specific applications, and technology, which Project Physics does not stress. Others may be so culturally disadvantaged and academically handicapped that quite different materials may be needed. We do hope to have a course that will appeal to many of the two million per year who have been rejecting any study of physics.

While many of our potential students will attend college, this is not of prime concern to us. We are attempting to provide high school students with an exciting course treating fundamental physical ideas in a humane context. Clearly we must appeal to more girls than are now enrolled in physics. Likewise, we must judiciously restrain the use of mathematics to essential instances, and then assume no more than a previous exposure to introductory algebra.

We have as yet little evidence about student acceptance of such a course, but the few straws in the wind blow in a pleasing direction. In ten schools which this year have teachers who used the materials last year, enrollments in the Project Physics course increased fifty per cent. The only teachers we have lost from our trial group have withdrawn because they joined the working team in Cambridge, moved to new schools, or had leaves of absence. Our fifty-five teachers this year feel that this course, which with their help is still evolving, is teachable and does appeal to many students who would not enroll for some other physics course. This gives us courage to proceed with the thousands of details which still must be handled.

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## PROJECT PHYSICS IN THE CLASSROOM

(DRAFT OF TALK AT AAPT MEETING, 1 FEBRUARY 1967)

F. James Rutherford

Suppose you were to walk into an American high school five or ten years from now to look at physics instruction. What are you likely to see? The answer, I believe, is that far more than today it will depend largely upon which particular school you walk into, who the physics teacher happens to be, which particular class among the many physics classes being taught in that school you happen to step into, and even which particular year you happen to visit that teacher in that classroom. It now seems altogether possible that within a decade diversity and variation will become predominant characteristics of physics teaching in the schools, and that this will permit, if not require, the physics teacher to reassert his central position as the chief designer of the course he teaches.

This diversity, which those of us who are working on Project Physics see possible—and coming, will manifest itself in several ways. At the first level, it will appear in the form of a multiplicity of courses. Some schools will be teaching only the "traditional" physics, or only PSSC, or only Harvard Project Physics; other schools will offer two or three of these basically different approaches to physics instruction. In time still other physics courses will appear and find their places among these. We at Project Physics believe this multiplicity will be all to the good, which is why we ask the teachers in our participating schools not to drop whatever other physics course they are currently teaching. We urge them instead to enlist additional students so that one or more classes of Project Physics can be added without giving up any of the existing sections or courses.

Now while the teacher of introductory physics will eventually have the opportunity to select from among several distinctly different courses (different in content, structure, emphasis, approach, style and intended audience) that should not be the end of it. Any one course development project can either actively promote variation in instruction, or in effect discourage it. Project Physics elected to advocate variety. If you visit our trial schools today, you will find large qualitative and quantitative differences in course content, and even larger differences in the mode of instruction being used. In short, you will find not one Harvard Project Physics course, but many.

Practical considerations, as well as educational and psychological theory, suggested the direction taken by Project Physics. As you look out at the schools in this country you see that, like it or not, great diversity exists. Schools vary in economic resources, in the age and utility of their classroom and laboratory facilities, in the community esteem and support they enjoy, in the vision and courage of their administrators, in what everyone concerned perceives to be their primary goals, and in many other tangible and intangible ways. The most important sources of variation in the schools, of course, are the teachers and students.

There are large and well-known differences in academic preparation among teachers. Of the approximately 17,000 persons who teach physics in high schools, only a small fraction were undergraduate physics majors. The few physics teachers who earn M.A.'s in physics are eagerly sought by—and all too often succumb to the enticements of—industry and junior colleges. Nevertheless, in spite of such lures, and, indeed, in spite of the career frustrations and unsatisfactory working conditions that tend to drive the physics teacher out of the profession, it does happen that some extraordinarily well-prepared teachers are to be found in the high schools. Furthermore, physics teachers, whatever their differences in preparation, tend to have their own —but differing—notions about what topics need to be emphasized, on how much content is suitable for their own students, and on how a class can best be operated.

The students filling the schools of this country are not all alike in academic ability, in what interests them in school and in life, in emotional commitment to education, in career expectations, in family background, or in regard to all those other "individual differences" about which we in education have been able to do little but talk. Further, if we compare the students who are already committed to taking physics and the large group which is not so interested, it is clear that the latter group is much more heterogeneous. The physics courses presently in the schools are not very different from one another as far as this diverse group is concerned. Physics must seem to them to be monolithic, something to be taken on its own terms, regardless of the student's individual tastes—tastes which tend, by definition of this group, far more toward the humanistic, philosophical, technological, sociological, and other non-preprofessional aspects of physics. These students are a mixture of a great variety of atoms and molecules, with many different valences.

There is all that diversity out in the real world of students, teachers, and schools, and I believe that there are no educational or social developments in sight likely to change that situation in the forseeable future, even if we wished it to be changed. It seems a matter of practical good sense, therefore, to accept diversity as a fact of life, and to build enough flexibility into our physics course to accommodate and even to take advantage of that diversity.

But do not think Project Physics reluctantly accepted that "practical" position with a shrug of despair. Far from being disturbed by the existence of diversity, we applaud it and wish to foster rather than restrict it. Thus our job, as we see it, is not to improve an existing physics course, since to do only that would be to contribute very little to the cause of multiplicity and variation. Instead, we took our first task to be the development of a physics course different from any existing ones in content, emphasis, and intended audience. Furthermore, we felt that our course, in and of itself, ought to be designed to permit and indeed to encourage variation. Thus we have been trying to develop a physics course that allows a teacher to complement his strength and supplement his weaknesses, that makes it possible for him to take into account student differences, and that is workable within a wide variety of school situations.

Such flexibility will necessarily place the teacher in a central role and require him to make key decisions about what will constitute "his" Project Physics course, and about how to teach it. But then, most teachers want, as a matter of personal pride and self-satisfaction, to do more than just teach someone else's course "as directed."

And in this they are right, for high school physics, or any other successfully taught course, must deeply involve the teacher. It must be teacher-directed—not so much in having the teacher take class time in lecturing (on the contrary!), but rather in the decisions that the teacher will make in finding a course and a role which will be congenial to him. The physics teacher must be involved in shaping his own course instead of becoming merely a loudspeaker at the end of a cable or an audio-visual handyman.

Even if there were not a persuasive ideological argument for the teacher having a strong role in course design there would be a strong practical one. Courses simply are not made by curriculum development groups. All a group such as Project Physics can do in the long run is to furnish tools, advice, training, and an esprit. A course is made in each separate classroom after the starting bell has rung for the lesson and the door is closed. The Pre-college Physics Project of the American Institute of Physics, investigating possible ways of increasing physics enrollment and strengthening teaching, came to this conclusion (Physics Today, October 1966): "No existing physics course adequately serves the large body of students who are not scientifically inclined...but it is also apparent that students rely more on the individual teacher than on a written course of instruction and that the most important element in the learning process is a well-trained teacher."

Flexibility, then, is being designed into the Project Physics course. This flexibility will exist with regard to content, instructional media, and mode of instruction. Eventually the teacher (and his students, if the teacher wishes) will be able to select a significant portion of the content of the physics course (up to about 1/3); he will have available a large variety of integrated instructional materials from the various media; and he will be able to adapt the course to his preferred mode of instruction even if (indeed, especially if) his preference is for a highly individualized, student-centered approach.

Let me treat the multi-media aspect of the course first. The "course" is composed of some number of "units" joined together. Typically, each unit is made up of the components displayed here.

1. Student guide, or textbook
2. Student laboratory guide and apparatus
3. Physics Reader
4. Programmed instruction booklets
5. Achievement tests
6. 8mm silent film loops
7. 16mm sound films
8. Overhead projector transparencies with multi-color overlays

Each of these components is described more fully in the Appendix to this pamphlet.

Other materials are designed as needed. For example, a film strip has been prepared made up of actual sun photographs. Students can make measurements of the changing apparent diameter of the sun, and then plot the orbit of the earth. In another case stroboscopic photographs of collision events (the same events, incidentally, shown in film loops used by the students) are printed on sheets of paper and are distributed to those students interested in doing careful quantitative work. In still another case, a computer program, a film loop, and a classroom experiment all may be tied together. This allows an interested student who has access to a high speed computer to perform on it essentially the same experiment that is being done in the lab by graphical iteration.

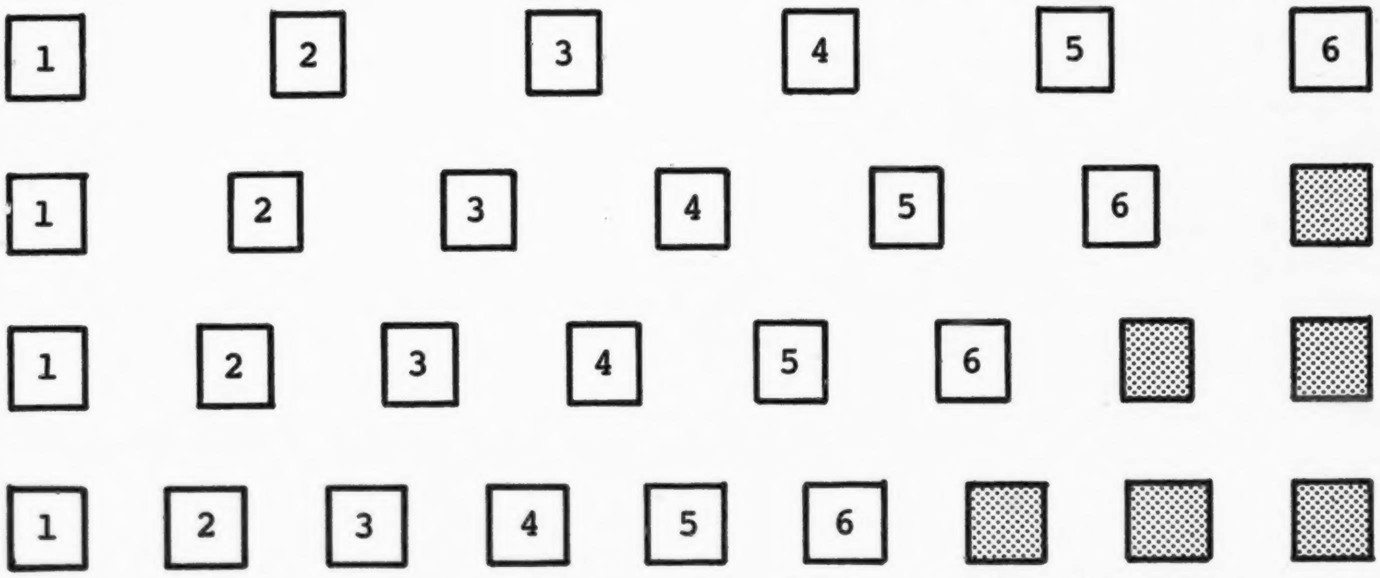
By now it should be clear that the quantity and diversity of instructional materials being prepared for each unit far exceeds the needs of any one student. But we have found that it takes a large pool of multi-media materials to be able to come to terms with the great diversity of students, teachers, and school situations. It is the task of the teacher with help from the Project to select from among the materials.

There is a danger in this approach. It is that unlimited flexibility could very well degenerate into infinite variety, presenting the teacher with an unmanageable task and confronting the student with a course lacking structure and continuity. Project Physics has been able to avoid this danger by adapting a unit structure. The basic course is made up of the six basic units described by Dr. Holton. The topics in these units are studied by all of the students taking the course. This is the core on which all else is built. Flexibility comes not from neglecting these topics but rather from the multi-media, multi-modal approach to these topics, and from the addition of supplemental topics to the basic course.

It is our expectation that every Project Physics class will complete at least the six basic units. A class made up of very slow and poorly prepared students working under adverse conditions might take a full year to complete the basic course. While they will not have completed as much physics perhaps as is contained in the books for other courses, at least what they do study will have structure, will be complete in itself, and should have meaning for them. The students will be better off than if they had completed only a fraction of a much longer course, and certainly better off than if they had no physics course at all.

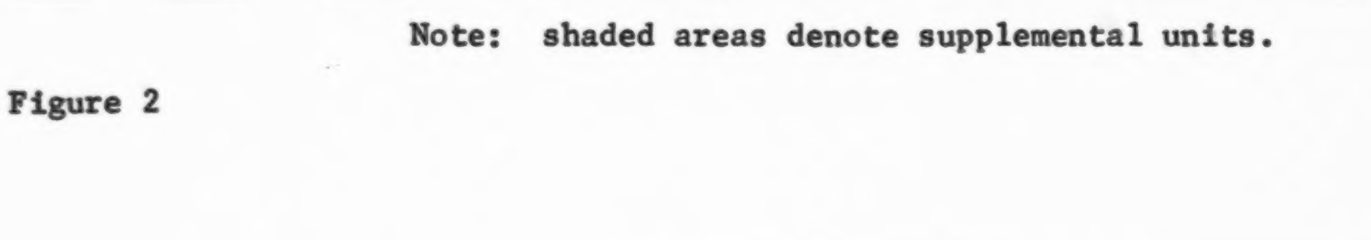
But what about more able students working under more favorable circumstances? For these the course during a nine and one-half months school year, will not be six units long, but rather seven, eight, or nine. The teacher (or if the teacher wishes, individual students or groups of students) will select these additional units from an array of about fifteen or twenty so-called supplemental units. Each of these units will be multi-media in the same sense as each of the basic units. Some of these additional units are historical and philosophical (such as one on the nature of discovery in the physical sciences), some are focused on the laboratory, (one on electricity and electronics, for example) some have an engineering bias (one on nuclear reactors), some deal with connections between physics and other sciences (biophysics), and some deal with physics in a theoretical manner (special relativity).

The value of having a pool of supplemental units readily available is that it immediately becomes convenient to construct many different versions of the Project Physics course by the selection and arrangement of units. The simplest way to organize the course is shown schematically in Fig. 1. Each rectangle stands for one unit of work. Notice that one class may cover as much as 50% more material than another. If for any one of these, the teacher selects the additional units, then every member of a given class covers the same material (though not necessarily at the same depth or with the same emphasis). On the other hand, some teachers elect to let students select the additional units, in which case during the latter part of the year the students work as subgroups or individuals. It should be added that some of the supplemental units are designed so that they can appropriately be studied before the end of the basic course. Hence an arrangement such as shown in Fig. 2 is possible.



Note: shaded areas denote supplemental units.

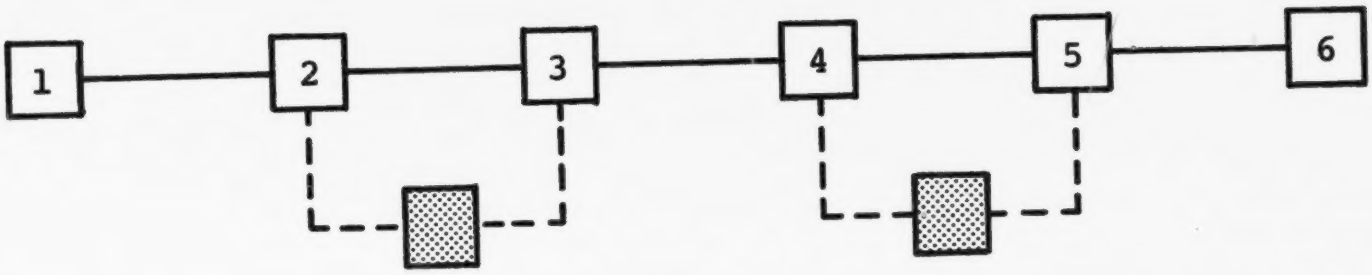
Figure 1



Note: shaded areas denote supplemental units.

Figure 2

For the teacher who prefers to have his entire class proceed at the pace of the slower students without boring the brighter ones, a branching arrangement of units is possible. This is shown schematically in Fig. 3. Thus while the slower students take the full school year to go through the six basic units, some of the others will be expected to do 1 or 2 additional units during the same period of time. In order to make this branching scheme feasible, we are trying to develop instructional materials for each supplemental unit that can be used by students with a minimum of help and direction from the teacher.



Note: shaded areas denote supplemental units.

Figure 3

Other variations in structure are of course possible but perhaps this is enough to demonstrate the immense flexibility that is gained by the unit structure. The whole "course" is designed by adding together matched components— not by doing surgery on a single integrated course.

Does it take an extraordinarily talented teacher using a unique teaching strategy in order to take advantage of a flexible multi-media course? It now seems certain that the answer is no. We already have substantial evidence from our participating schools that this kind of a course can be organized and taught successfully by a variety of teachers using many different modes of instruction. Thus, one of our jobs is to convince teachers that they can teach this kind of a course without having to change their teaching style. Once they have seen this is true from their own experience, we would like to be able to help teachers experiment with other modes of instruction if they chose to.

First consider the teacher who teaches by what could be called the traditional method. In his classes, lectures, discussion sessions, laboratories, the occasional use of audio-visual aids, homework assignments, and tests make up the day-in day-out routine. During his first year of teaching Project Physics, it is likely that such a teacher would want to confine himself to the basic course, and concentrate on coming to know the course, its structure and materials well. To aid him in this the Project is preparing a combination teacher's guide and resource book. The patterns set by pre-

ORGANIZATIONAL Worksheet for CHAPTER 3

## SAMPLE PAGE FROM TEACHER'S GUIDE

| TEXT SECTION | rough time suggestion for text treatment | EXPERIMENTS | DEMONSTRATIONS | TEACHING AIDS | STUDENT ACTIVITIES | READER ARTICLES | PROBLEMS |
|---|---|---|---|---|---|---|---|
| 3.1 What are complex motions? | one day | | | | A3.1 MAKING HARMONOGRAMS | | |
| 3.2 The question of direction: vectors. | | | D3.2a VECTOR ADDITION OF VELOCITY<br>D3.2b NON-COMMUTATIVITY OF ROTATIONS | T3.2 TRANSPARENCY: VECTOR OPERATIONS | | I.3 | 1,2, |
| 3.3 Projectile motion | one day | | | T3.3 TRANSPARENCY: PARABOLIC PROJECTILE MOTION | A3.3 PHOTOGRAPHING PROJECTILE MOTION | I.6 | |
| 3.4 The superposition principle. | | | D3.4 STROBE ANALYSIS OF SUPERPOSITION PRINCIPLE FOR FREE FALL | T3.4 TRANSPARENCY: PARABOLIC PROJECTILE MOTION | | | 3,7, |
| 3.5 What is the path of a projectile? | | E3.5* TRAJECTORIES | D3.5 SIMULATION OF A PARABOLIC PATH | T3.5 TRANSPARENCY: PARABOLIC PROJECTILE MOTION | A3.5a LAUNCHING PROJECTILES<br>A3.5b CALCULATING SPEED OF A STREAM OF WATER | | |
| 3.6 Galilean relativity. | one day | | D3.6a FRAMES OF REFERENCE<br>D3.6b INERTIAL VS. NON-INERTIAL REFERENCE FRAMES<br>D3.6c MONKEY-GUN EXPERIMENT | T3.6a FILM LOOP: A MATTER OF RELATIVE MOTION<br>T3.6b PSSC FILM: FRAMES OF REFERENCE<br>T3.6c TRANSPARENCY: FREE FALL<br>T3.6d TRANSPARENCY: PARABOLIC PROJECTILE MOTION | | | 5, 6, |
| 3.7 Circular motion. | | | D3.7 GENERATING A CYCLOID | T3.7 PROGRAMMED UNIT: "ANGULAR MEASURE" | | | |
| 3.8 Describing uniform circular motion. | | | D3.8 EFFECTS OF ROTATING REFERENCE FRAMES | | A3.8 MEASURING PERIOD OF VARIOUS MOTIONS | | |

vious curriculum groups have been very useful to us in this regard. Part of the Teacher Guide's job is to describe all of the materials available and to key them into the appropriate places in the text. Options are pointed out, although the teacher in his first year may chose to use relatively few. During his second year such a teacher would probably add one or more supplemental units and at the same time use the original basic units in a way that would take better advantage of the resources available. We envision that in a period of about three years a "traditional" teacher would become extremely adept at selecting and utilizing multi-media materials and would in fact be changing his course from year to year.

It may be, however, that the most advantageous use of multi-media instructional materials will not come through the traditional approach to teaching. For this reason we are working on what we speak of as a multi-media systems approach. In those Project Physics classrooms where this approach is used there is very little lecturing; instead the students actively and systematically progress through a carefully designed set of experiences utilizing film loops, programmed instruction booklets, laboratory experiments, and the other media. The teacher manages the system and helps individual students as needed, but he does not act as a primary giver of physics information.

The Project is also testing the course under circumstances in which the mode of instruction approaches the extreme of individualization. In these classes, the teacher outlines the goals of the class, sets the timetable, makes all of the instructional materials available to the students, and then simply works with the students as individuals or with small groups. The emphasis in this approach shifts from "teaching" to "learning." The student is made to understand that the responsibility for learning is his, not his teacher's, and that in accepting this responsibility he will be given substantial freedom to decide which aspects of the material he personally chooses to concentrate on and latitude in deciding how to go about the task of learning. Wherever we have tried this approach so far, the student response in terms of performance and sustained interest has far exceeded our expectations.

The main point in talking about modes of instruction is not to show that some are better than others, but only that the diversity and flexibility inherent in the structure of the Project Physics course allows the course to be taught by teachers using a wide range of styles and approaches. We have delineated three approaches and are designing guides for each. After a teacher has used one or more of these, he may find that it is reasonably easy for him to design his own approach using some or all of the matched components that are available. If this happens we will be delighted, for as I said at the beginning, it is our shared belief that the teacher can eventually come to be the chief architect of his own course.

## APPENDIX

# Harvard Project Physics

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## LABORATORY EXPERIMENTS

In each unit, four or five laboratory experiments with equipment designed by the Project have been designated as basic. Additional exercises devised by the Project are considered optional or to be conducted by the teacher as demonstrations or lecture experiments. These are all described in the Teacher's Guide for each unit. In addition, a laboratory guide has been written and is provided to each student. This guide is not a rigid recipe book, but is a brief description of the experiment, with cautions concerning the proper use of the equipment and suggestions for further inquiry. Some examples from this year's schedule of laboratory exercises are:

Trajectories of projectiles, tracing out the parabolic path.

Rocket thrust table.

The orbit of Mars using data from actual photographs.

Stepwise approximation to an orbit by applying periodic impulses by means of a central force.

"Seventeenth-century physics experiment," a replication of Galileo's inclined plane experiment using a water-clock.

Conservation of momentum using a linear air track.

Liquid surface accelerometer for quantitative measurements.

Brownian motion.

Current balance, finding the force between two currents and between a current and a magnetic field.

Wave motion, using phonograph turntables to illustrate simple harmonic motion, sine curves, superposition, etc.

Electromagnetic Wave Propagation (Microwaves).

Measurement of elementary charge with a modified Millikan experiment.

Measurement of other fundamental constants, e.g. e/m of electron, Planck's constant.

Exponential decay, simulated with randomizing devices.

Cosmic Ray Background Counting.

Cloud chamber, with and without an applied magnetic field.

Autoradiography.

The equipment of these experiments is simple, and its operation is familiar to most physics teachers. To simplify teaching, learning, and budget keeping, the Project has tried to select and develop basic equipment having multiple uses throughout the year, and sturdy enough to be used again from year to year.

## PROGRAMMED INSTRUCTION

Programmed Instruction is another kind of teaching aid that has been developed in close coordination with the other materials in Harvard Project Physics. The emphasis has been on two kinds of programs: remedial and adjunct. Adjunct programs generally do not repeat material covered in the text, and indeed the text writers have often omitted the lengthy, full treatment of material that could better be handled through programs (e.g. vectors).

Remedial programs assist weaker students with concepts used in the course. The programs themselves are not self-contained and independent, but rather are integrated closely with the text and laboratory exercises. Within the programs, the student who is having trouble with the material is occasionally advised to consult with his teacher.

The primary objective of the programs is to teach certain skills and concepts. Their style is, however, designed to assist the student to learn how to learn. Students are not merely conditioned to give correct answers; the way students acquire the concepts is as important as the concepts themselves. In view of these factors, the need for programmed material is greater during the earlier units; hence the programs so far developed are pertinent to the first unit. The titles are: Review of Graphs, Vectors, Velocity and Acceleration, Angular Measures, Proportions and Newton's Laws, and Measurement and Precision.

Three or four more programs will reach the field testing stage during 1966-67. During the summer of 1967, several more will be written. Versions of the six existing programs are currently being revised on the basis of field tests this year.

## FILM LOOPS

The 8 mm film loop, or single-concept film, has been gaining wider and wider acceptance in the schools around the country. Its versatility, however, has not yet been exploited to the fullest extent. The majority of the film loops developed by Harvard Project Physics are quantitative or semi-quantitative motion pictures, from which teachers or students can obtain measurements of significant physical quantities. The Project is publishing film notes for each of the loops, to assist the students to interact positively with the films rather than to remain passive spectators. In addition, some loops have been constructed to serve as quiz items; students can be required to analyze (or otherwise respond to) the phenomena being presented on the screen as a test of their knowledge of physics.

High speed photography has made possible the visual presentation of phenomena that are usually not observable in the laboratory. The slow motion effect also permits fairly accurate measurements of the displayed scene so that, for instance, conservation of momentum can be established. It should be emphasized that not all the settings of these film loops are in the laboratory; many of the basic concepts are illustrated in scenes familiar to high school students. Thus, the teacher can either introduce a concept by beginning with a familiar situation, or illustrate a previously learned concept by reference to the concrete situation. The teacher can even test the understanding of an abstract concept with such a film loop.

The films will be produced in color, although this year's experimental version has been released to our participating schools in black-and-white. During 1966-67, nearly one hundred films have been scheduled for production, and in 1967-68, a hundred more are scheduled. The experimental versions of most of the following films will be revised and improved during 1967-68.

Titles of some of the film loops are given below:

Uniformly Accelerated Motion

Acceleration of a Jet Aircraft on the Runway

The Four-Minute Mile

Inertial Forces on an Elevator

Retrograde Motion of a Planet - Ptolemaic Model

Retrograde Motion of a Planet - Current Model

Colliding Freight Cars

Two-Dimensional Collisions

Explosion of a Cluster of Objects

Random Walk

Standing Waves

Photon Interference

Plotting Electric Fields

Deflection of Electrons by Fields

Models of the Atom

Deflection of Radioactive Particles by a Magnetic Field

PHYSICS READER

One of the basic premises of the course being developed by Harvard Project Physics is that students need to see physics as a creative and cultural activity in its own right, and as a significant component of the intellectual matrix that defines civilization in general. The Physics Reader is one attempt to appeal to the varied interests of different students by presenting selections from the writings of scientists and of non-scientists who have been affected by the growth of physics.

The Physics Reader is designed for browsing, although some teachers may wish to suggest or recommend specific readings to their students. When individual students appear to have interests in these directions, teachers can use the Reader, along with the bibliographies in the Teacher's Guide, to help the student in his individual studies.

The current experimental version of the Reader consists of a separately bound booklet for each unit, plus one additional booklet entitled ABOUT SCIENCE, which contains more general and philosophical articles not belonging specifically with any one unit. The tables of contents from the first few Readers are given below:

## ABOUT SCIENCE

| | |
|---|---|
| The Value of Science | Richard Feynman |
| Style in Science | John Rader Platt |
| The Reasonableness of Science | W. M. Davis |
| On "Scientific Method" | P. W. Bridgman |
| How to Solve It | G. Polya |
| Failure and Success | C. P. Snow |
| A Conversation with Einstein | Leopold Infeld |
| Four Pieces of Advice to Young People | Warren Weaver |
| Scientific Cranks | Martin Gardner |
| The Seven False Images of Science | Gerald Holton |
| Close Reasoning | Fred Hoyle |
| Discovering Scientific Method | H. Ruchlis |
| Effect of Weak Wings | S. Tolansky |
| Merits of the Quantitative Method | Rudolf Carnap |
| The Nature of Concepts | Gerald Holton |
| On the Method of Theoretical Physics | Albert Einstein |
| Letter from Thomas Jefferson, June 1799 | Thomas Jefferson |
| The Vision of Our Age | J. Bronowski |
| One Scientist and his View of Science | Leopold Infeld |
| Chart of the Future | Arthur C. Clarke |

## UNIT 1

| | |
|---|---|
| On Being the Right Size | J. B. S. Haldane |
| Motion | William Kingdom Clifford |
| Speed | W. W. Sawyer |
| Mechanics | J. L. Synge and<br>B. A. Griffith |

| | |
|---|---|
| Kinematics | Arnold B. Arons |
| Galileo's Discussion of Projectile Motions | Gerald Holton and Duane H.D. Roller |
| The Dynamics of a Golf Club | C. L. Stong |
| Newton and the Principia | C. C. Gillispie |
| Axioms, or Laws of Motion | Isaac Newton |
| Particle at Rest | Edwin F. Taylor |
| Coordinates and Transformations | Hermann Bondi |
| Newton's Laws of Dynamics | R. P. Feynman, R. B. Leighton, and M. Sands |
| Representation of Movement | Gyorgy Kepes |
| The Scientific Revolution | Herbert Butterfield |
| The Effect of the Scientific Revolution | Basil Willey |
| Relative Motion | Isaac Newton |
| Newton and Relative Motion | Ernst Mach |
| The Fourth Dimension and Relativity | Leopold Infeld |
| The Size of Life | Erwin Schrödinger |

UNIT 2

| | |
|---|---|
| The Black Cloud | Fred Hoyle |
| Into the "Depths of the Universe" | Helen Wright |
| Copernicus: His Aim and His Theory | Stephen Toulmin and June Goodfield |
| The Starry Messenger | Galileo |
| Kepler's Celestial Music | I. Bernard Cohen |
| The Garden of Epicurus | Anatole France |
| The Force of Gravity | Michael Faraday |
| Universal Gravitation | R. P. Feynman, R. B. Leighton, and M. Sands |

| | |
|---|---|
| Gravity Experiments | R. H. Dicke,<br>P. G. Roll,<br>and J. Weber |
| Roll Call | Isaac Asimov |
| An Appreciation of the Earth | Stephen H. Dole |
| The Great Comet of 1965 | Owen Gingerich |
| The Sun and its Energy | George Gamow |
| A search for Life on Earth at Kilometer Resolution | Steven D. Kilston,<br>Robert R. Drummond,<br>and Carl Sagan |
| Space, the Unconquerable | Arthur C. Clarke |
| The Life-Story of a Star | Marshal H. Wrubel |
| A Bird's Eye View of Our Galaxy | Harlow Shapley |
| The Life-Story of a Galaxy | Margaret Burbidge |
| The Expansion of the Universe | Hermann Bondi |
| Cosmic Opera—Mister Tompkins and Cosmological Theories | George Gamow |
| Negative Mass | Banesh Hoffmann |
| The Quasar | G. Feinberg |
| Troilus and Cressida | William Shakespeare |
| Hudibras | Samuel Butler |
| My Father's Watch | John Ciardi |
| Proposition I: The Law of Areas | Isaac Newton |

## UNIT 3

| | |
|---|---|
| The Motive Power of Fire | Sadi Carnot |
| Mr. Watt's 1796 Account of the Origin of the Steam Engine | James Watt |
| The Steam Engine Comes of Age | R. J. Forbes and<br>E. J. Dijksterhuis |

| | |
|---|---|
| Energy | William Thomson<br>and P. G. Tait |
| The Great Molecular Theory of Gases | Eric M. Rogers |
| On the Kinetic Theory of Gases | J. Clerk Maxwell |
| The Law of Disorder | George Gamow |
| The Law | Robert M. Coates |
| The Arrow of Time | J. Bronowski |
| Maxwell's Demon—Mister Tompkins' Version | George Gamow |
| Fermentation | Antoine-Laurent Lavoisier |
| The Conservation of Energy | R. P. Feynman,<br>R. B. Leighton,<br>and M. Sands |

## UNIT 4

| | |
|---|---|
| Action at a Distance | James Clerk Maxwell |
| Experimental Determination of the Law of Electric Force | Henry Cavendish |
| About Historic and Modern Machines for the Generation of Static Electricity | Albert G. Ingalls |
| The Relationship of Electricity and Magnetism | D. K. C. MacDonald |
| Introduction to Waves | Physical Science Study Committee |
| Wave Motion and Acoustics | Robert Bruce Lindsay |
| Ears: Architects of Harmony | Arthur H. Benade |
| Experiments and Calculations Relative to Physical Optics | Thomas Young |
| Velocity of Light | A. A. Michelson |
| On the Induction of Electric Currents | James Clerk Maxwell |

| | |
|---|---|
| Light and Electricity | Richard C. Maclaurin |
| Scientific Imagination | R. P. Feynman, R. B. Leighton, and M. Sands |
| Electromagnetic Theory | Max Born |
| A Mirror for the Brain | W. Grey Walter |

## SOUND FILMS

Some fine short sound films on scientific topics within physics, made by other projects or commercial houses, are referenced in the Teacher's Guides, and the Project will continue to recommend their use in conjunction with the topics covered in the units. Films dealing with the broader historical and sociological aspects of physics are not so easily found. Harvard Project Physics has therefore supported and encouraged the development of this type of film.

(a) A grant from the Office of Education is making possible a documentary (unposed, unstaged) black-and-white sound film which has been following the activities of a group of experimental physicists at work over a two-year period on a developing problem in high energy physics. Using a wide-gap spark chamber, an easily visible and not difficult to understand device whose construction is followed in the film, the group of scientists at the Cambridge Electron Accelerator is investigating electron-positron pair production.

The emphasis in the film is on the life and work of physicists. Professors, research assistants, and graduate students are being filmed both at work, in offices and laboratories, and at home, in their studies or with their families. Supporting activities to the experiment such as electronics, carpentry, machine tooling and office work are also being filmed to show that many different activities are involved in a typical experiment in modern physics.

The film is to be completed by May, 1967, and will run from forty to fifty minutes. No knowledge of physics is required to follow the film; it should therefore be suitable for a wider distribution than high school courses in physics. The past experience of the film-makers has been with long, anthropologically oriented films. With the assistance of physicists, they have begun to edit the large amount of footage already accumulated.

This film, when completed, will serve three important functions related to the general aims of Harvard Project Physics. In the first place, the "cinema veritè" method permits the honest direct reportage of the story of how a real physics experiment came to be defined and was executed. Secondly, students will observe more about the lives of a variety of young scientists than merely their "official" work. Often references to scientists have been too closely tied to the published digest of their scientific contributions, while insufficient attention has been given to their personalities and living patterns. The film will also provide an interesting contrast of the procedures of a fairly typical though large physics project today with those of earlier centuries. Readings about the practice of science are all too often related only to this earlier period, and a number of false ideas may be removed by such a film.

(b) The Project has been cooperating on a study of the feasibility of an authentic documentary biography of one of the foremost physicists of this century, Enrico Fermi. An experienced team of film-makers from the National Film Board of Canada has located a great many documents, still photographs, and existing movie films relating to Fermi's life. In addition, filmed interviews with his former colleagues and students are being made in this country and abroad. Supervising this project is an ad hoc committee consisting of Kenneth T. Bainbridge, Laura Fermi, Robert Gardner, Bruno Rossi, Alice Smith, and the Project Co-Directors.

Agencies here and abroad have offered their assistance in this project. The U. S. Atomic Energy Commission, for instance, has given assurances of full cooperation; the chief of the Audio-Visual Branch of the AEC is acting as liaison personnel with the Project.

## OVERHEAD PROJECTOR TRANSPARENCIES

To extend the ways in which overhead projector transparencies can be used, Harvard Project Physics has developed a series of multi-colored transparencies with overlays. These devices enable the teacher to project accurately drawn diagrams on a large screen, and, using the overlays, to analyze the significant features of the picture. Some overlays are designed to be moved across the basic transparency, thus simulating the effects of motion, and in effect producing a sequence of stroboscopic views. Other overlays can be used for quizzing students on the elements of the depicted scene.

Harvard Project Physics is testing about fifty experimental versions of overhead projector transparencies during 1966-67. The set of transparencies associated with any unit will be accompanied by a teacher's handbook describing ways to use the overlays. Suggestions about ways of using overlay transparencies are being incorporated into the Teacher's Guide for each unit. The integration of the various teaching media is indicated by the fact that some of these transparencies illustrate tasks arising from experiments, while others are scaled versions of incidents that can be found in the film loops. Clearly, no one is required to use all these items, yet, if a teacher did use a transparency to discuss, say, a concept illustrated in a film loop, then the visual overlap will assist the student to follow the discussion.

An idea of the variety of topics for which transparencies have been developed may be gained from the following list of examples, largely for the first few class meetings:

James Ryun's First "Four-Minute Mile" Data

Approaching a Limit - Instantaneous Speed

Geometric Derivation of $s = 1/2at^2$ Equation

Geometric Relationship Between Velocity and Acceleration

Retrograde Motion (Vector Analysis)

Motion Under Central Force

Interference of Waves

## ACHIEVEMENT TESTING

Many teachers like to devise their own examinations. The Teacher's Guide for each unit has several suggestions to assist the teacher in the construction of good questions. A rich supply of sample items is also supplied. For those who see the value of standardized tests, on the other hand, Harvard Project Physics will make available several equivalent forms of unit tests. Each item in these tests has validation data, and the reliability of the tests as a whole, with national norms, will be provided.

Each test covers the entire content of a unit. The items are analyzed in terms of the skills required for their solution and of the topics covered. Numerical problems are kept to a minimum, which is consistent with our general de-emphasis on mere computation. Mere recall of specific facts is similarly minimized. Questions of interpretation, however, play an important role.

The system for categorizing items is adapted from Bloom's Taxonomy and Nedelsky's recent Science Teaching and Testing. Besides evaluating items for the kinds of cognitive activities required, the Project has also made sure that the unit examinations cover all the important concepts within the unit—the historical and philosophical issues as well as the physics.

Harvard Project Physics has developed, and is supporting further research and evaluation of tests for other dimensions of student changes besides achievement. Affective measures and non-obtrusive tests are under constant development and evaluation by Project staff. It is an important part of the educational philosophy of the Project that students not only learn physics but also avail themselves of the opportunity to learn to like science.

## EVALUATION

During the academic years 1964-65 and 1965-66, the main effort of the Evaluation Group was directed towards course improvement, while plans were being made for future activities. Modifications of course materials were influenced greatly by the written comments from the field consultants (teachers actually teaching the course), discussions at Feedback Conferences, test results and student responses on questionnaires. In addition to these external sources of information, some internal criteria were used to evaluate the course material. Such factors as readability, (measured by standardized vocabulary tables and the average sentence length) served to gauge the suitability of the writing with respect to the intended audience. Student reaction to the course was determined not only by written responses, but also by such factors as the changes in enrollment in Project Physics sections.

During the present year, the direction of interest of the Evaluation Group has been turning towards questions more appropriate to consumer information and educational research rather than only course improvement. Results of this research are being reported at professional meetings such as the National Association of Research in Science Teaching, and in the professional journals. The Evaluation Group also provides the setting and facilities for more specialized research, which at this time is the basis of at least five doctoral dissertations in graduate schools of education.

Quite generally, the Evaluation Group is trying to discover what "changes" occur in "what kind of students" using Project Physics materials with "what kinds of teachers." Efforts this year have been made to give operational definitions of the phrases enclosed in quotation marks, and to devise a research design that will give unambiguous answers to specific questions. Experience with the pilot study this year has led the research design for 1967-68, which will involve a randomization over the 17,000 teachers currently teaching high school physics.

Further information about the activities of the Evaluation Group can be obtained by writing directly to Wayne W. Welch at the Project in Cambridge.

## TEACHER TRAINING

Harvard Project Physics will take its place in the curriculum of our high schools only if there are teachers who understand its aims and are prepared to implement them. Consequently, teacher education has been a central concern of the project from the beginning.

The first steps towards initiating a teacher education program were two Teacher Education Conferences, at Cambridge and San Francisco, in the Spring of 1965. About 150 physicists and science educators from institutions which have in the past trained a substantial number of physics teachers attended these conferences. Many of the current plans had their origin in these conferences. Also from the deliberations came suggestions for the conduct of our first 6-week Briefing Session for participating high school teachers, held in the summer of 1966 at Pomona College under the direction of Professor Jack Miller.

These experiences have suggested three guidelines for our future teacher education plans:

1) Teaching of Project Physics requires, of course, both a knowledge of physics and the ability to use the variety of instructional materials developed by the Project. Teacher education, therefore, must be a joint effort of physicists and science educators. (The participants of the two conferences, who represented both professions, felt that the opportunity to discuss teacher education problems jointly there was of great value.)

2) To reach a substantial fraction of physics teachers, Project Physics must explore a variety of approaches, from extension course programs for individual teachers to institute courses for groups.

3) Experienced Harvard Project Physics teachers are an important resource in the teacher education effort.

Summer institutes are the first organized teacher education effort for which the project has made firm plans. In addition to a 1967 Briefing Session at Wellesley College for teachers participating in the evaluation of the Project course, there will be a Project Physics Summer Institute at Creighton University directed by Professors Arnold J. Moore and Thomas H. Zepf. A Summer Institute at Clark College directed by Professor O. P. Puri will also use Project materials. Applications for 1967-68 Inservice Institutes have been submitted to the National Science Foundation, and we encourage and will cooperate with prospective directors of additional institutes. A brochure with suggestions for the conduct of such institutes has been prepared by the Project, and is available to those who wish to use our materials. Inquiries may be made directly to Stephen S. Winter at our Cambridge office.

An avenue for teacher education which promises to become increasingly important is the Cooperative College-School program. This program brings together a college and the high schools in its vicinity. In addition to providing more substantial help to the new teachers through a follow-up during the academic year of the summer training, this program permits wider use of experienced Project Physics teachers as key instructional personnel. We hope that Project Physics area centers will develop in several places throughout the country, and we expect to provide guidelines for the administration of these centers.

Somewhat longer-range teacher education plans include the preparation of films and video-tapes for use in television and in institutes and area centers as well; the production of extension course packages including not only these films, but also film loops, slides, and taped directions, along the lines of the auto-tutorial method developed by Professor Postlethwait of Purdue for his biology course; and, of course, printed documents. Just as the technological inventions that are finding good use in the instruction are being widely adopted for the Project Physics course, so our teacher education effort will increasingly turn to these innovations to help achieve the desired results. Our involvement in teacher education is clear; the commitment has been made. The key to the success of this effort remains, however, with our colleagues in physics and science education departments throughout the country.

## FUTURE ACTIVITIES

The basic concern of the Project during the year 1966-67 is to review and revise the materials already produced in their experimental versions. In mid-1967 these materials should be available to participating schools in a form suitable for final evaluation. Throughout the year 1967-68 additional materials such as film loops, overhead transparencies, and programmed instruction booklets will continue to be developed in trial versions. Although the Project does not intend to continue producing materials for teaching physics for the indefinite future, it has a basic commitment to complete during the next two years the development of such materials as 8-mm film loops, about 100 more of which are scheduled for 1967-68; programmed instructional material for which there is a need of many more booklets; and the rounding out of Supplemental Units that are currently being written.

Another area of concern for the Project involves the use of this course in special environments. Unintentionally, courses tend to be developed chiefly for middle-class students in middle-class schools. If this is not to be true for Project Physics, what modifications need to be made for poorer, and richer, schools? What adjustments need to be made for disadvantaged students? For superior students?

The problem of special environments also includes the use of Project Physics materials in foreign countries, with their own cultural presuppositions, distinct educational curricula, and indigenous staffing problems. The Project is currently planning a conference in the summer of 1968 for educators from foreign countries who are interested in adapting our materials.

As indicated, the Project has its own research and evaluation design, but obviously other models can and should be used. Project Physics is eager to cooperate with qualified groups who want to use our materials for educational research, or wish to make independent evaluations of our materials. Some groups might also provide alternate models for dissemination. Our own procedures for the dissemination of our course can undoubtedly be improved, and it is important to find out how best to disseminate new teaching materials.

Finally, Project Physics hopes to establish or participate in demonstration and information centers throughout the country, where experienced field consultants would serve as nuclei for in-service education of nearby colleagues as well as serving as a convenient resource for those seeking to learn about the functioning of Project Physics. The directors of Project Physics are receptive to inquiries and suggestions concerning these, and related topics.

## NEWSLETTER

Interest in the progress of Harvard Project Physics during the past two years has led to the establishment of a Newsletter, which is mailed free upon request. You can obtain the Newsletter by writing:

Harvard Project Physics
Pierce Hall, 29 Oxford Street
Harvard University
Cambridge, Massachusetts 02138

If you would like to have your name placed on the Newsletter mailing list please fill out the attached card.

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